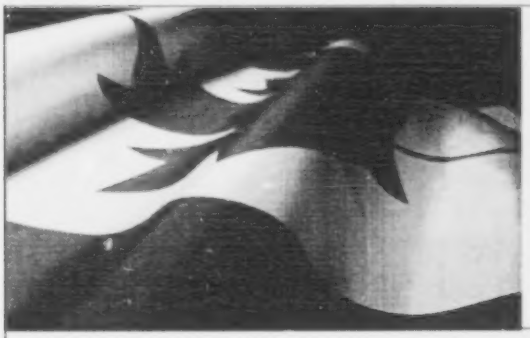

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Canada's Low Business R&D Intensity: the Role of Industry Composition

by

Aled ab Iorwerth [1]

Abiorwerth.aled@fin.gc.ca

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Abstract

This paper looks at the reasons for Canada's low business research and development (R&D) intensity. R&D performance across OECD countries is examined, and a detailed decomposition is undertaken of differences between Canadian and U.S. R&D levels across industries. Canada's low aggregate R&D performance hides high research intensities in some research-intensive industries. The smaller relative size of these industries, however, combined with low R&D intensity in the motor vehicle and service industries, account for the weak aggregate R&D performance in Canada.

Résumé

L'auteur examine les raisons pour le faible niveau de l'intensité en recherche et développement (R&D) dans le secteur privé au Canada. La performance en R&D dans les pays de l'OCDE est examinée et une décomposition détaillée est faite pour les différences entre les niveaux de R&D des industries aux États-Unis et au Canada. La faible performance agrégée du Canada en R&D cache des intensités en recherche élevées aux seins de plusieurs industries qui utilisent la R&D de façon intensive. Cependant la plus petite taille relative de ces industries en plus d'intensité très faible dans les industries des véhicules automobiles et des services enfreignent la performance globale en R&D au Canada.

1. Introduction

An often-made observation when comparing Canada with other countries is the low level of private-sector R&D expenditures undertaken in Canada. The 2004 Budget, for example, notes how, "Canada's relatively weak R&D performance appears to be concentrated in the private sector".[1] A paper from *Statistics Canada* notes that over the 1990s, "while Canada's business R&D figures improved, its overall level of business R&D, both as a percentage of GDP and as a proportion of all R&D, remained lower than the high R&D performance countries except Ireland and all of the G-7 except Italy."[2]

The purpose of this note is to accumulate some basic facts to account for low aggregate R&D intensity in Canada. Using mostly OECD data for 1999, differences in R&D levels between Canada and the U.S. are decomposed into differences in the industrial structure of the economy and different R&D intensities across industries. It does not seem that this exercise has been done previously in Canada, although a similar exercise for the U.K. was conducted in Griffith and Harrison (2003).[3] These facts are then examined to see whether traditional explanations to explain low Canadian R&D intensity can be supported. Traditional hypotheses to explain low Canadian R&D intensity are the high degree of foreign ownership, large natural resource sector, and the small scale of Canadian firms.

In the more direct accounting sense, this paper shows that low aggregate R&D intensity may be explained by two themes. Firstly, although aggregate research intensity is, in some sense, 'low', it is precipitate to conclude that individual Canadian industries are undertaking too little research. There are industries in Canada, particularly some of the more research-intensive, high-tech industries, that are very research intensive by world standards, and research intensity has been increasing in some of these. But these industries are relatively smaller (as a proportion of GDP) in Canada than in the U.S. There may not be enough firms in Canada in these industries, or Canadian firms may not have grown large enough. For these industries, it is not clear whether further increasing research intensity within firms would be attainable because of their already high research intensity by world standards.

Secondly, there is low research intensity in the motor vehicles industry and the service sector. Although the motor vehicles industry is relatively bigger in Canada than in the U.S., its research intensity is very low in comparison. In services, although Canadian R&D intensity is relatively high compared to other OECD countries, R&D intensity lags relative to the U.S. While detailed service data are incomplete for the U.S., this weaker performance seems to be emanating from the wholesale and retail industry.

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[1] pp. 301, Budget Plan, 2004.
[2] Lonmo and Anderson (2003).
[3] An exception, discussed later, is Whewell (1999).

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These findings have some implications for the traditional explanations advanced, and mentioned above, to explain low Canadian aggregate R&D intensity. There is no support for the preponderance of natural resources in Canada as a direct explanation for low R&D intensity. This paper does not provide direct evidence on the other two hypotheses. But foreign investment probably explains low R&D intensity in motor vehicles but, at the same time, it may help to increase R&D intensity in some other industries. International evidence does point to firm size not being a robust influence on R&D intensity.

It should be emphasized that this work is an exercise in accounting, not economics, and policy or causal conclusions should not be drawn too quickly. For example, these types of exercises cannot indicate how easy or difficult changing R&D intensity might be. In fact, given how research intensive some Canadian industries appear to be, it is not immediately obvious whether the amount of firms' R&D could be further increased. Finally, R&D expenditures are an input measure of innovation and do not capture the outputs.

One should of course also highlight that making international comparisons of R&D expenditures may be prone to inaccuracies both because of the inherent difficulty of making international comparisons but also the particular difficulties relevant to R&D. Although the OECD has established some principles to try to establish international comparability—the Oslo manual—it is difficult to know whether these are fully implemented in each country.[4]

Section 2 summarizes the prevailing views by observers of Canadian R&D and some potential reasons for the low aggregate level. Section 3 discusses some of the academic literature on the importance of controlling for an economy's industrial composition when trying to explain economy-wide patterns of R&D investment. Section 4 discusses the data on R&D in general and the decomposition analysis. Section 5 concludes.

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[4] Another issue, raised in Baldwin et al. (2004), is whether R&D expenditures, as currently, measured, are the most appropriate measure of knowledge used. A small open economy, such as Canada, is more likely to license technology from other countries, and these payments for others' knowledge are not included in R&D expenditure. However, it is also unclear conceptually what R&D should be measuring. Currently, R&D is seems to be aiming at capturing knowledge production. The proposal of Baldwin et al. (2004) is aimed more at knowledge use. While it is important to make this distinction and to note the impact on the knowledge intensity of production, it may be that externalities are more closely linked with knowledge production, and the stock of knowledge in a country may be more closely linked to R&D actually done within a country rather than imported. Payments to license technologies, a measure of expenditure on the use of knowledge, are not necessarily linked to innovation, and may also be heavily influenced by tax planning. Nevertheless, it may be that such measures of knowledge use should be more carefully accounted for in the stock of machinery and equipment investment, for example, or at least reported separately and publicly. One could also argue that, *in extremis*, knowledge available for use is uniform across all countries.

2. The prevailing view of Canadian R&D

General views on Canadian R&D

The available material on the state of research in Canada yields parts of the puzzle but no comprehensive and detailed picture exists. In general, it would seem that there has not been a thorough and wide-ranging investigation to explain low aggregate business R&D intensity.[5] Furthermore some unwarranted conclusions may have been drawn from research and data that had more limited goals. There seem to have been changes in the amount of R&D undertaken in certain industries in Canada over the last decade so one should also be careful since conclusions from empirical research from the early 90s may no longer be valid. David et al. (2000) note that even empirical research on R&D in the U.S. has been plagued by methodological problems because empirical analysts have worked in the absence of a clear theoretical understanding of R&D and the influence of policy on it.

Attention is usually concentrated on the headline number of aggregate R&D intensity where intensity is measured as a proportion of GDP. Figure 1 shows the recent experience of some OECD countries. It is usually inferred from Canada's relative poor performance on this indicator that Canada's R&D intensity is uniformly poor. For example, the Conference Board of Canada has undertaken extensive benchmarking of the Canadian economy by comparing Canada's performance with that of leading countries.[6] In particular, they have benchmarked Canada's performance in innovation, using the following measures: i) total R&D as a percentage of GDP; ii) total industry spending on R&D; iii) higher education spending on R&D; iv) external patent applications; and v) the proportion of the labour force that are researchers.[7] From benchmarking these indicators they assign a ranking of 'poor' on Canada's innovation performance.[8]

Summarizing these results, the *Globe and Mail* reported, "Canada is near the bottom of the pack in terms of creating new ideas. Canadian investment in R&D relative to GDP, is only two-thirds that of the United States and even worse when compared with Sweden…But the board also says Canada's business community is investing too little in R&D, worker training and new machinery and equipment."[9]

Reported statistics on aggregate R&D expenditure led Roger Martin and Michael Porter (2001) to state that their research, "on the innovative capacity of nations reinforces the

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[5] In previous research, Palda (1993) only seems to look at research intensities without looking at the contribution made by each sector to GDP. He does make the important point however of the need to look at more detailed industry data rather than relying only on aggregate data.

[6] For discussion of innovation in Canada, see pp. 25 and pp. 65 in Conference Board of Canada (2003) and also Barrett (2001).

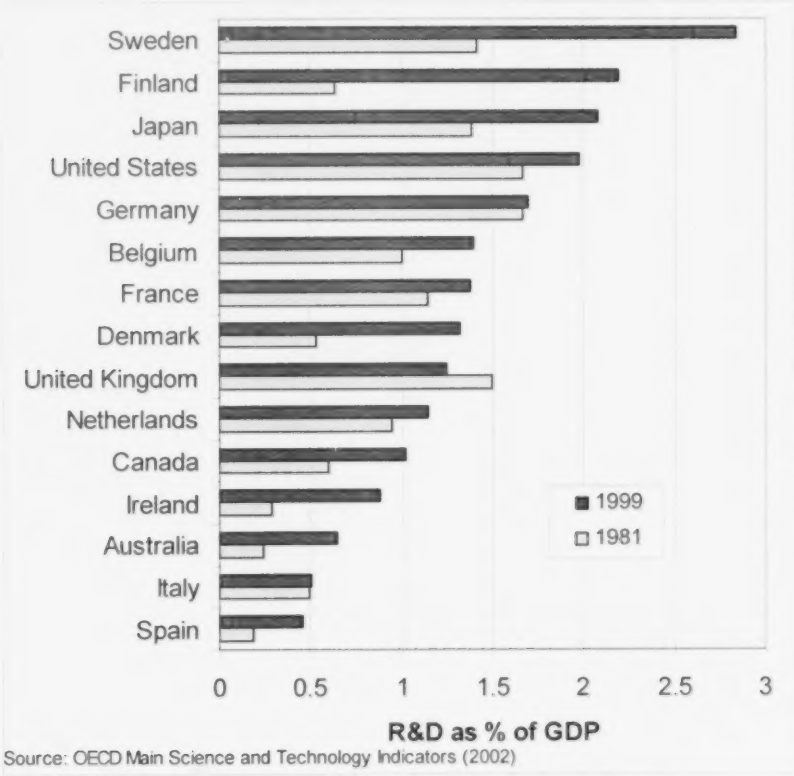
[7] It should be noted that some of these variables are highly correlated across countries, e.g. R&D as a percentage of GDP, and the proportion of the labour force that are researchers. It is therefore unclear whether having several indicators of the same phenomenon leads to additional information.

[8] Summarized in Conference Board of Canada (2001).

[9] Little (2003).

weaknesses highlighted in the Global Competitiveness Report …Canada ranks squarely in the second tier of countries on the Innovation Index."

Figure 1: R&D as a Percentage of GDP, 1981-1999



Source: OECD Main Science and Technology Indicators (2002)

The concentration on 'supply-side' measures

One can think of R&D heuristically in a simple supply and demand framework.[10] The supply of R&D is governed by the availability of researchers in a particular field and the equipment that they use. Consumers demand innovative goods from firms who in turn have a direct demand for the factors that supply R&D. Firms' demand for these factors will be a function both of factor costs and of the benefits they obtain from selling these innovative goods.

It seems that policy advisors have inferred from low aggregate R&D intensity that policies to encourage research within each firm are desirable, i.e. there is an inference that low aggregate R&D intensity implies low firm R&D. Advisors concentrate on policies to lower the cost of undertaking R&D—operating on the supply side in the above framework—through increasing the supply of factors that undertake R&D without

[10] Abstracting from such issues as indivisibilities, appropriability problems and spillovers.

necessarily worrying why exactly firms do not have a greater demand for R&D in the first place.[11]

Amongst the recommendations of the Conference Board for boosting innovation is greater spending by firms on R&D, although there are no specific explanations of how this can be done.[12] In particular, it states, "several indicators suggest that Canadian businesses have been under-investing, notably industry-financed gross expenditures on R&D…".[13] It further states "companies here spend less on R&D than those in other countries."[14]

De la Mothe(2001) examined Canada's low R&D intensity. He claims that if Canada wanted to move to the top five countries (in terms of R&D/GDP) then Canada, as a start, would have had to spend $27bn in 2000 rather than the $16-20bn that it did, hiring an additional 100,000 workers. But spending more on R&D without knowing where the demand is going to come from may lead to an inefficient outcome. Nonetheless, the Natural Science and Engineering Research Council (NSERC(2002)), for example, has taken such estimates to predict that major increases in the supply of graduate students are needed if Canada is to meet the goal of being in the top five in terms of R&D expenditure per capita and of replacing retiring faculty.

But these recommendations focus on increasing supply with no indication that the demand exists for such a supply. Such policies may be inefficient if the demand for research inputs is inelastic or the markets for inputs are open internationally. Increasing the supply of Canadian-trained researchers may lead to researchers going to work overseas rather than remaining in Canada. Ryoo and Rosen (2004) find that the supply of engineers in the U.S. responds rapidly to changing demand. If the structure of the Canadian economy were important in explaining aggregate R&D intensity then it would also seem that government policies that increase the supply of researchers would have to be carefully calibrated to match demand.

Causes of low Canadian R&D intensity

Other than exhorting firms to spend more on R&D, some work has been done to explain low Canadian R&D intensity. In general it would seem that there are three prevailing themes that have been advanced:

- Industry composition, and in particular the dependence of Canada on the resources sector,

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[11] Perhaps analysts have been too ready to pronounce whether a market failure exists. Boldrin and Levine (2004) suggest that if R&D has to be embodied in a good to be useful then it is less clear that a market failure exists. However, the market failure may have shifted to other parts of the economy, such as a higher price for machinery and equipment investment that embodies the R&D, as suggested by ab Iorwerth(2004).
[12] Other research by the Conference Board (Warda (1999)) shows that the price of R&D for small companies is very low in Canada.
[13] pp. 4 in Conference Board (2003)
[14] pp. 25 Conference Board (2003)

- The degree of foreign ownership,
- Whether Canadian firms are of sufficient size to affect the size of aggregate research.

It should be emphasized that these explanations are not true causal factors. Other deeper economic primitives are needed to explain these proximate causes, and these are discussed in the next section.

As an example of the usual reasoning, Canada's Innovation Strategy (released by Industry Canada and HRDC) states that,

> "R&D performed by Canada's private sector continues to lag behind major OECD countries. … To some extent this reflects the larger presence of foreign-controlled firms in Canada (which tend to spend more on R&D in their home countries), a smaller presence of high-technology firms (which tend to be the big R&D spenders), and the predominance of small firms in Canada (which have fewer resources to dedicate to R&D)."[15]

Andrew Sharpe suggests that the difference in R&D intensity between Canada and the U.S. "reflects both differences in industrial structure between the two countries, with Canada's relatively larger natural resource-related industries less R&D intensive, and the high level of foreign ownership in Canadian industry, with R&D concentrated in the home country."[16]

The OECD in its survey of Canada in 2000 stated, "Canada's R&D spending remains lower than the OECD average because of the economy's continuing orientation towards resource activity, where such spending is relatively low."[17] But in its review of science data, the OECD states, "manufacturing R&D expenditure is skewed towards high-technology industries in Canada, Ireland and Finland."[18] Taking such statements in isolation may yield some confusion.

Peter Nicholson (2003) believes that part of the answer is industrial structure with the Canadian economy "still relatively dominated by industries that exhibit low R&D intensity regardless of where they are located—e.g. resource-based manufacturing". But he also notes that "on a matched industry basis, Canadian R&D spending (as a share of value-added) is in most sectors far below that of the United States. This is probably because many of Canada's large, technically-advanced firms are affiliates of foreign (usually U.S.) multinationals. … The auto industry is a striking example". He

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[15] pp. 40 Industry Canada, 2001.To support these arguments, the study cites Tang and Rao (2001) and work by the Conference Board discussed elsewhere in this note.
[16] pp. 19 in Sharpe (2003).
[17] Footnote. 8, pp. 160, OECD (2000).
[18] Pp. 24, OECD(2003).

notes however that R&D intensity in the communications equipment and semiconductors sector exceeds that of the U.S.[19]

The Parliament of Canada produced a report discussing Canada's innovation performance (Parliament (2001)). They conclude that the size of a country's GDP is not relevant to R&D intensity (because of exceptions like Sweden) but that geographic size may be a hindrance because of the reliance on natural resources. Smaller countries can concentrate on developing a comparative advantage in innovative industries. After discussing the impact of foreign ownership, the committee seems to have concluded that the industrial structure of Canada was a primary reason for poor R&D performance in Canada.[20]

A consensus seems to exist that the reason for poor aggregate R&D intensity in Canada is the structure of the economy (particularly the preponderance of natural resources) and a high degree of foreign ownership. Some applied research has been done lately on the impact of foreign ownership in Canada with results tangentially reported on the effect of firm size.

Specific Views on the Impact of Foreign Ownership

This section briefly summarizes some of the views on the impact of the degree of foreign ownership in Canada on research intensity. The suspicion is that Canadian firms will rely on spillovers from research undertaken in the U.S. for developing innovative products. Hence Canadian firms will feel less need to undertake their own research.[21] The aggregate data available tend to support this view. The top panel of Figure 3 shows that total R&D as a percentage of total sales has been increasing in Canadian firms over the 90s whereas such growth has been fairly flat for foreign-controlled firms. R&D as a percentage of sales across the whole economy is higher in Canadian firms than in foreign firms.

However this aggregate picture does not control for the detailed industry composition of the Canadian economy where the picture is a little bit more confusing. There are two aspects to the composition that suggest that care should be taken in interpreting the aggregate numbers:

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[19] It should be noted that the OECD data used to support this argument were older than are currently available. There have been increases in Canadian R&D intensity in some industries (particularly pharmaceuticals) since the date of publication.

[20] It should be noted in passing that both Sweden and Finland used to be resource-intensive economy with Sweden producing large amounts of iron ore and Finland having extensive forestry operations. One of the important firms in Finish forestry was Nokia. http://www.nokia.com/nokia/0,8764,1125,00.html.

[21] Cohen and Levinthal(1989) however argue that undertaking R&D is necessary in order to be able to absorb the spillovers from R&D in other countries. The implications of this work have been extended by Acemoglu et al. (2003) to argue that the social rate of return for R&D undertaken in countries not at the research frontier is even higher than in the lead country. In turn this methodology has been used to suggest empirically that the social rate of return to innovation is higher than thought (Griffith et al. (2003)).

1. There is a stark difference in the importance of R&D by foreign-controlled firms in manufacturing and services. From the middle panel of Figure 3, manufacturing R&D-to-sales ratios in Canadian firms are increasing and are higher than their foreign-controlled counterparts. This picture holds within industries that compose manufacturing as well (with the exception of aircraft), as seen in Figure 4. But, as seen in the bottom panel of Figure 3, the reverse holds in services: the foreign R&D-to-sales ratio is increasing and was much higher by 1999. The R&D intensity by Canadian-controlled service industries is relatively flat. The picture in services also holds within component service industries (with the exception of communication services and management consulting services), as seen in Figure 5.

2. Foreign firms do much of the R&D done in Canada: for example, foreign-controlled firms do the majority of research in some high-tech industries such as pharmaceuticals, as seen in Figure 6.

The extent to which foreign-controlled firms undertake R&D are reported as R&D-to-sales ratios. The ratios used in the rest of this paper are R&D-to-value added ratios, which allows one to make an exact decomposition of aggregate numbers such as R&D-to-GDP ratios. This decomposition cannot be done directly with R&D-to-sales ratios. It may be that there are systematic differences between Canadian and foreign-controlled firms that alter these ratios. For example, foreign-controlled firms may import more intermediate inputs and have less head-office staff leading to their value added being a smaller proportion of sales. The R&D-to-value added ratio could therefore be higher for foreign firms than suggested by R&D to sales ratios. Consequently, making inferences about the impact of foreign ownership on aggregate R&D intensity (as a proportion of GDP) is not immediate.[22]

A further difficulty is that one cannot infer from lower R&D intensity by individual foreign firms or industries that the effect of higher foreign ownership is to lower aggregate R&D intensity. It is logical to say that if foreign controlled firms had a lower R&D-to-sales ratio in all industries that foreign firms lower average research intensity across industries in Canada. However, foreign firms could conceptually have lower R&D-to-sales ratios in all industries and still contribute to increasing aggregate R&D intensity (R&D/GDP) in Canada because of their distribution across industries. As an extreme example, suppose that 90 per cent of R&D done by foreign-controlled firms in Canada were done in the pharmaceuticals industry, a high research intensity industry. Even if the R&D-to-sales ratio within foreign pharmaceutical firms were lower than their Canadian equivalents, the fact that this foreign R&D was concentrated in a high-R&D intensity industry should imply that foreign firms were contributing positively to aggregate R&D intensity. Hence, conceptually, to assess the impact of foreign ownership on aggregate Canadian R&D intensity would require examining the effect of both the intensity and the distribution of the amount of R&D done in Canada by foreign-controlled firms. The two points made above—combined with the pattern of R&D

[22] We do not have data on the foreign-to-domestic ratios for value added and R&D in order to be able to undertake this analysis.

investment in pharmaceuticals in Figure 4 (which shows much higher R&D intensity by domestic pharmaceutical firms in Canada) and Figure 6 (which shows that over three-quarters of pharmaceuticals R&D is done by foreign firms) suggest that this should be a concern in reality as well when examining the Canadian economy.

Bearing in mind these caveats, two analyses in Canada have tried to isolate the effect of foreign ownership on aggregate R&D intensity by controlling for other factors, such as firm size, and to a certain effect for industry composition. Their results are summarized in the next section.

Existing Research on Foreign Investment and R&D Intensity in Canada

Tang and Rao (2001) look at firm data from 1985-1994 and find that "foreign-controlled firms in Canada, after accounting for other factors (such as firm size and industry), spend significantly less on R&D than Canadian-controlled firms." The authors use a dummy variable for high-tech industries that they classify as: Chemicals, petroleum and coal products; Electrical and electronic products; Industrial machinery. Aggregating industries in this manner may be problematic because, as the results later in this note indicate, important differences within even narrowly defined industries may be lost.

In the regression results that they present in their Table 5, it is noticeable that the R-square indicates that only 3 per cent of the variation in R&D intensity is explained by controlling for foreign ownership. The other measured factors account for a further 18 per cent. Hence even if the econometric results are valid, foreign ownership has low explanatory power. This conclusion is compounded by the fact that their raw data only includes relatively large firms. From the previous discussion however, it would seem that a regression analysis would only capture differences in average R&D-to-sales ratios across industries. The impact of factors that change R&D-to-sales ratio does not necessarily have any direct implications for explaining R&D-to-GDP ratios.

Baldwin and Hanel (2000, 2003) examine the behaviour of foreign firms in Canada. Firms are classified only into a small number of aggregate sectors: core, secondary and other, to represent their degree of innovativeness. However, as will become clear in the next section, there may be significant microeconomic differences within industries in the 'core' sector.

In their analysis the authors look only at the incidence of R&D, i.e. the probability of undertaking R&D in Canada. There are no estimates of the amount of R&D undertaken (and they cite another study for evidence of R&D expenditures by firms). Hence the fact that many more foreign than domestic firms may be undertaking R&D but are only spending a dollar each would be reflected in a higher incidence of R&D without shedding light on total expenditures on R&D.

They find that foreign firms innovate more frequently than Canadian-owned firms, but at the same rate as Canadian multinational firms. They conclude, "... the evidence unequivocally supports the hypothesis that foreign-owned firms contribute significantly

to technological progress in Canadian industry."[23] However, given that their results do not give any measure of the quantity of research expenditure (let alone a measure of research output), only on the likelihood of undertaking research, it is unclear what the authors mean when they say 'contribute'.

What are the trends in the international flows of R&D?

There has been a steady increase in the proportion of R&D that is financed from abroad, particularly in Canada and the U.K., as seen in Figure 8. On the other hand, the proportion of R&D financed from abroad in Finland is very low, implying that much of its large increase in R&D expenditures arose from domestic sources. Even if the R&D intensity of foreign-owned firms were lower, there is no reason why Canada should not try to capture some of this investment.

As mentioned previously, the degree of foreign ownership is not necessarily a true economic causal factor. Given that multinationals have a wide variety of countries in which they can undertake R&D, they may be affected primarily by (amongst others) the availability of skilled workers or the tax burden that they face. R&D intensity patterns by foreign firms may therefore be a proxy for deeper causal factors. Paying attention to such primary causal factors looks like becoming increasingly important as more and more R&D is done overseas.

Foreign affiliates of U.S. firms are doing increasing amounts of R&D abroad. In 1985, overseas R&D accounted for 6.0 per cent of U.S. industry's total R&D (domestic plus overseas) but rose to 13.1 per cent in 2000. R&D spending by U.S. firms remains however much more concentrated in the U.S. (at 87 per cent of total spending) than are the employees (74 per cent of total number) or sales (72 per cent of total) of U.S. companies.[24]

Although U.S. expenditures on R&D overseas has increased rapidly, the share of R&D performed by U.S. affiliates in Canada as a percentage of total overseas R&D has declined steadily from 13 per cent in 1982 to 9.5 per cent in 2000. Despite this decline in share, nominal expenditures by U.S. firms in Canada increased 72 per cent over the 1989-1999, increasing 20 per cent over 1996-2000. Internationally, however, foreign R&D expenditure by U.S. firms increased 129 per cent over 1989-1999 and by 40 per cent over 1996-2000.

Given this pattern of increasing investment by foreign firms in R&D, it is becoming less obvious that a high degree of foreign ownership should inherently be associated with lower R&D intensity. Empirical research in the U.K. has shown that the growing share of R&D undertaken by foreign-owned companies appears to have a significant positive impact on the aggregate level of R&D expenditures in that country.[25]

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[23] pp. 306, Baldwin and Hanel (2003).
[24] Table 4-24 of NSF(2004).
[25] Becker and Pain (2003).

Firm size

Some studies in Canada have examined the impact of firm size on R&D intensity. However, these studies have usually only noted these results in passing. A difficulty with such results is that the impact of firm size on R&D intensity may be sensitive to the sample of firms used. In Tang and Rao (2001), 58 manufacturing firms with positive R&D expenditures are examined, but excluding firms with zero R&D expenditures may skew the results. The authors then report that R&D (as a proportion of sales) falls with firm size, but this result may be an artifact of their sample rather than a statement that is true for Canada.

Using a much larger sample, Holbrook and Squires(1996) look specifically at R&D across firm size in Canada. They find that the R&D-to-sales intensity declines with increases in firm size after controlling for industry and foreign ownership. They find that foreign firms in Canada are larger than Canadian firms and that it is this size differential that explains their lower R&D-to-sales ratio rather than their country of control.

But analysis in the U.S. and other countries suggests that the nature of the sample and the importance of outliers are important (it is not clear how important these outliers are in Canadian data). Controlling for these effects, studies in other countries have found that there is no robust relationship between firm size and R&D intensity. Some of the stylized facts about R&D and firm size (drawn from research in many countries) are given in Figure 2.

Figure 2: Some Stylized Facts on the Effect of Firm Size [26]

1. The likelihood of a firm reporting positive R&D investment increases with firm size. The probability approaches one for the largest firms;

2. Within industries, among firms that perform R&D, R&D increases monotonically with firm size (in whichever category of size). It is not possible to reject the argument that R&D varies proportionally to firm size across the entire firm size distribution. Differences in firm size explain over half of intra-industry variation in absolute R&D activity.

3. For the firms that perform R&D, the number of patents and innovations per dollar of R&D decrease with firm size and/or the level of R&D. Hence small firms account for a proportionately large number of patents and innovations relative to their size.

4. A considerable number of firms report zero R&D, so that the distribution of R&D intensity across firm size is highly skewed.

[26] Cohen and Klepper (1996) and Klette and Kortum (2004). Discussion of research and productivity requires a greater discussion as given in Klenow(1996). For example, the research productivity (as opposed to labour productivity) of large firms may be smaller because they can spread the fixed costs of research over more projects and therefore go further down the marginal productivity curve.

Section Summary

Three principal arguments seem to have been put forward as reasons for low Canadian R&D intensity: a relatively large resource sector, a high share of foreign-owned firms and the small size of Canadian firms.

In general, there has not been a systematic effort to assess the contribution of all potential factors in explaining low aggregate R&D intensity. Two analyses examined the impact of foreign ownership in Canada but came to opposite conclusions. The results from Tang and Rao (2003) suggest that the degree of foreign ownership has a negative impact on R&D intensity whereas Baldiwn and Hanel (2000,2003) suggest that foreign firms contribute significantly to R&D in Canada.

Both papers seem to fail to carefully account for inter-industry differences. The tendency to associate firms with groups of industries may give misleading results, as there may be significant inter-industry differences even within the high-tech industry. For example, the degree of foreign ownership may be important in explaining low R&D intensity in some industries but help in others.

Results later in this paper show that it is important when trying to explain aggregate R&D-to-GDP intensity that industry composition be analyzed carefully. Results show for example that the R&D-to-value added ratio for foreign pharmaceuticals firms is lower for foreign firms but that foreign firms conducted over 80 per cent of R&D in this industry in 1997. A complete analysis of the role of foreign firms in explaining aggregate R&D intensity would require looking at both the proportion of total R&D done by foreign firms in an industry as well as the intensity with which they undertake that R&D. Therefore, one cannot say that existing research has provided a definitive answer to the question of whether foreign ownership lowers aggregate R&D intensity in Canada.

There seems to be a general presumption that the size of the resource sector is important in explaining the aggregate gap. From a policy perspective, many analysts seem to have inferred from the low aggregate business R&D intensity that each individual firm or industry must be doing little R&D. However, to our knowledge there exists no full industrial decomposition analysis of the Canada-U.S. R&D intensity gap. The decomposition analysis performed in the Section 4 shows that low R&D intensity is not widespread among Canadian industries.

3. Why might industry composition be important – a review of the literature

It has been well established in the economics literature on R&D that there are substantial differences in R&D intensities across industries. Scherer (1980), for example, using 1975 data showed that half of total U.S. R&D expenditure occurred in the electrical equipment and aircraft-missile sectors.

Scherer (1967) was amongst the first to show empirically that much variation of R&D intensity could be explained by industry fixed effects. To emphasize the importance of industry effects, Cohen and Levin (1989) summarize the ensuing literature as saying that measured industry characteristics (discussed below) can explain about 50 per cent of industry differences in R&D intensities but measured firm characteristics (e.g. cash flow, diversification) can explain only about 10 per cent of firm differences. Work by Cohen, Levin and Mowery (1987) shows that after careful examination of the data[27], assigning a firm to an industry accounts for half of R&D intensity differences across firms. Stated more generally, belonging to different industries explains half of the differences across firms' spending on R&D. On the other hand the size of a firm only accounts for around 1 per cent of the different R&D intensity across firms.

These differences across industry reinforce the idea of why we have definitions of industries in the first place. Jaffe (1986) classifies firms into "technological groups" according to the area where those firms patent, and shows that there are spillovers between firms within these technological groups. But then he notes that his data does not allow him to distinguish between industry effects and technology effects implying that 'technology' and 'industry' can be synonymous.[28]

The explanations advanced for inter-industry differences in R&D intensity have been numerous (many started by Joseph Schumpeter) but many have been discarded. Although earlier literature found relationships between market structure or firm size with R&D intensity, controlling for further factors eliminated the importance of these initial explanations. The importance of differences in firm size across industries has been discarded as an explanation because empirical results have been found to be very sensitive to small changes in details such as the degree of industry aggregation or controlling for other characteristics. It is likely that the optimal firm size/R&D

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[27] Essentially this task involves eliminating a small number of important outliers.

[28] Industry differences in R&D and technology change may therefore be important in explaining productivity growth. Geroski (1991) shows how innovation in some sectors (broadly engineering and chemicals), and the use of knowledge embodied in new products from these sectors are important in explaining productivity growth. He finds that the use of new products has a greater impact on productivity growth than the production of the innovation themselves. Englander et al. (1988) note the importance of chemicals and machinery in industrial R&D and their high research intensity. The authors find that industry-specific R&D was more important in explaining cross-country TFP growth than country-specific R&D variables.

relationship will vary by industry.[29] Because of this interaction, it is unclear if the problem of endogeneity between size and innovation has been adequately resolved.[30]

Explanations advanced: The effect of industry characteristics on R&D intensity

The usual candidates that have been advanced to explain inter-industry differences in R&D-intensity, and have some more robust empirical support, are:[31]

i. Market size and growth in demand
This argument that rapidly growing industries would spur R&D activity is associated with Schmookler (1966). Furthermore, it has been argued that larger potential markets would promote R&D. Empirically this proposition has been difficult to implement because of the difficulty of obtaining a measure for market demand. Some evidence to support this argument is found in Scherer (1982).

ii. Technological opportunity
With advances in science (that may be exogenous) some new inventions will be of greater use to some industries than to other. For example, scientific advances in biochemistry will more readily flow to the pharmaceutical industry.

Using the results of questionnaires sent to firms, Klevorick et al. (1996) find that the strength and sources of technological opportunity contribute importantly to explanations of cross-industry variation in R&D intensity. On a similar theme, Cohen et al. (2002), find that university research is only important to industrial R&D in a small number of industries, particularly pharmaceuticals.

iii. Appropriability differences
If firms make a new invention there may be some industries where they can hang on to the benefits of this invention, either by virtue of secrecy within the industry or a greater ease of patenting. In other industries new inventions will rapidly disseminate to other firms, thus increasing the incentive to free ride on the research efforts of others and leading to lower R&D intensity in that industry. Results in Levin et al. (1985) suggest that appropriability conditions are important in determining the rate of innovation (but has a weaker effect on intensity).

The research seems to show that R&D intensity in each industry is largely a function of characteristics particular to that industry (rather than more general issues such as the degree of concentration or firm size). Furthermore, the degree of scientific or technological advance in each industry seems to be the most prominent causal factor in

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[29] This conclusion has led to theoretical work that can capture within-industry differences in firm performances, e.g. Klepper(1996) and Klette and Griliches (2000).
[30] All of the pre-1989 literature and many of the methodological problems are discussed in Cohen and Levin (1989).
[31] See Cohen and Levin(1989) and Klenow(1996).

explaining industry differences. These explanations have been advanced, and tested, however in a closed economy setting.

What are the implications of industry composition in an international context?

Examining the impact of industry composition in an international context is more complicated. One has to explain why R&D intensity differs across and within industries and across different countries. Clearly some of the three aforementioned factors play a role in an international context as well. Because of differences in patent laws, appropriability may differ across countries, but one might think that the technological opportunity was fairly uniform across the world.

The first factor—market size—and its interaction with scale economies may have an impact on R&D intensities. Scale economies imply that it is better to centralize R&D in a few facilities so that the R&D can supply a particular market. For auto production, it may be better to centralize R&D for North American manufacturing. Firm ownership (and because consumer tastes and regulations may be guided more by the U.S. market) may explain why R&D is located in the U.S. The same pattern may play out in the EU with ownership or historical reasons indicating where R&D takes place.

On the other hand, the supply of skilled researchers may be a more important factor in other industries, such as in the pharmaceuticals industry. Economies of scale may be achieved if there is a sufficient local supply of skills. Similarly it may be easier in certain industries to locate R&D where the skills are available but to locate production elsewhere. If there does not need to be an immediate and tight link between production and R&D, or if product R&D can be separated from process R&D, then R&D intensities may differ substantially within industries across countries.

Another factor that may manifest itself more at the international level is the degree of substitutability between different forms of knowledge transfer. In certain industries, knowledge can be developed through R&D or absorbed by investing in machinery and equipment that embodies that knowledge. In other industries, this option may not be so readily available (such as pharmaceuticals potentially).

Policy differences across countries may also affect R&D intensity. Some countries have generous R&D tax incentives whereas others may concentrate on increasing the supply of skilled labour and/or lower corporate taxes.[32] Clearly controlling for the structural differences across countries, as well as policy differences, makes it difficult to establish in international comparisons what are the true causal factors that may explain international differences in R&D intensities.

Bloom et al. (2002) make some effort in this direction. Their objective is to examine the impact of changes in R&D tax credits in nine OECD countries on R&D intensity, and they do find a positive effect in the long run.[33] They have cross-country panel data and

[32] For discussion of tax differences for R&D over the last twenty years, see Bloom et al. (1997).
[33] They report a user cost elasticity of around 1.0 in the long run.

control for country and time effects. By introducing country fixed effects they are trying to capture differences in the quantity of skilled labour across countries (although there have been large increases in the number of researchers in some countries).

The authors replicate their work across twenty industries. They find that the R&D tax credit has a statistically significant effect in twelve of them, with relatively high elasticities in the drugs and medicines, non-ferrous metals, other manufacturing, instruments and wood products. The tax credit had an insignificant effect on radio, TV and communication equipment, and aerospace industries. These results might indicate that the R&D tax credit is not effective in those industries where R&D is a necessary part of business (although pharmaceuticals is an obvious counterexample). But the aerospace industry also receives substantial direct subsidies that would weaken the importance of a tax credit.

A similar methodology could be used to explain some differences in cross-country R&D averages. The importance of differences in the availability of researchers, government incentives, industry composition could be examined.

Controlling for industries in evaluating the R&D tax credit

These last results suggest that controlling for industry differences may be important when evaluating the effectiveness of the R&D tax credit. Studies that have evaluated the effectiveness of these credits do usually control for industry, but given the results in the previous section they should also allow for different elasticities across industries. Hall (1993) first differences her firm-level data (which gets rid of fixed firm and industry effects) and finds that the estimated response of R&D to tax price changes is higher as a result (the elasticity increases from 0.84 in the short run to 1.5 in the long run). Looking at Canadian firms, Dagenais et al. (1997) find similar results: they find an own-price elasticity of around 1.0 in the long run. They do not report results by industry but do control for industry composition.

Mamuneas and Nadiri (1996) estimate own and cross price elasticities across some manufacturing industries. They find different results across industries depending on the policy used but generally find that subsidies crowd out private expenditure whereas the tax credit is effective. On the other hand Ghosh et al. (2004), who do not take the sectoral composition of the economy into account and use only aggregate data, find the reverse.

4. Analysis

Data Sources and Other Preliminaries

All of the data used in this paper have been obtained from the OECD. Because data were not available for many countries in 2000, data for 1999 were used. The databases used were:

- OECD STAN database for Industrial Analysis;
- OECD Research and Development Expenditure in Industry Database

Own R&D intensity is given by R&D expenditure divided by that industry's value added. Aggregate R&D intensity is given by summing the R&D intensity in each industry multiplied by that industry's value added as a share of GDP.

$$\frac{Total\ R\&D}{GDP} = \sum_i \frac{R\&D_i}{Value\ added_i} \frac{Value\ added_i}{GDP}$$

Particular attention is given in this paper to R&D expenditures by an industry as a proportion of that industry's value added (as opposed to a proportion of sales or as a percentage of GDP).[34] Using R&D as a share of value added allows that aggregate R&D intensity gap with the U.S. to be decomposed into industry effects through a Bennet decomposition.[35]

The aggregate gap is then given by the sum of a) the intensity effect, given by

$$\sum \left(\frac{R\&D_t^{Cdn}}{VA_t^{Cdn}} - \frac{R\&D_t^{US}}{VA_t^{US}} \right) \cdot \frac{1}{2} \left(\frac{VA_t^{Cdn}}{GDP^{Cdn}} + \frac{VA_t^{US}}{GDP^{US}} \right)$$

and b) the structural effect, given by

$$\sum \left(\frac{VA_t^{Cdn}}{GDP^{Cdn}} - \frac{VA_t^{US}}{GDP_t^{US}} \right) \cdot \frac{1}{2} \left(\frac{R\&D_t^{Cdn}}{VA_t^{Cdn}} + \frac{R\&D_t^{US}}{VA_t^{US}} \right)$$

A difficulty with this approach is that some sectors (e.g. agriculture) undertake no R&D. Hence because the ratio R&D to value added is zero, the intensity and structural effects both equal zero by definition. This shortcoming will be addressed later.

The following discussion also looks at R&D intensity by industry over time. But one should be careful at looking at intertemporal R&D intensities. Nominal data presented

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[34] As shown in Becker and Pain (2003), using sector value added rather than GDP can change one's perception of the data quite dramatically.
[35] Diewert (1998).

over time may be distorted by the different evolution of prices across sectors, e.g. in the wages of biochemists versus the wages of engineers. The speculative boom of the late 90s may distort research data during that period. No corrections are made for these differences in this paper.[36]

Background

In this section, we look briefly at the overall picture for R&D and note some other patterns. From Figure 10, most countries in the OECD have seen increases in their research intensity (R&D/GDP) with particularly notable increases in Sweden and Finland. Clearly there is a fairly wide variation of R&D intensities across OECD countries.

R&D intensity as a percentage of total GDP is much higher in manufacturing, as seen in Figure 11. But not only is R&D undertaken by the private sector mostly in manufacturing, it is also heavily concentrated in a few industries: pharmaceuticals; office, accounting and computing machinery; radio, television and communication equipment; motor vehicles and other transport equipment. Figure 12 shows how much of total R&D is concentrated in these industries: across countries an average of 52 per cent of total research is done there.[37] In both Canada and the U.S. these industries account for about 5 per cent of GDP.

Explaining aggregate R&D differences is therefore to a large extent a function of explaining what happens in these manufacturing industries. The composition of aggregate research intensity (as a % of GDP) can vary quite markedly, depending on the importance of these sectors in the economy as well as intensity differences, as seen in Figure 13. Telecommunication research is a very large factor in Finland and the motor vehicles industry figures prominently in both Germany and Sweden. There is more research in the telecommunications equipment industry in Canada. In the U.S., research is fairly evenly distributed over all the high research-intensity manufacturing industries.

Figure 14 shows the research intensity for the service sector.[38] It would seem that an important factor in explaining differences in research intensity in this sector is the presence of research in the wholesale and retail sector. Large amounts of research are done in this sector in the U.S., Canada, Denmark and the Netherlands relative to other countries. However, one may need to be careful about whether R&D expenditures are allocated to the same industries across countries. Australia, for example, reports zero expenditures in wholesale and retail but relatively large expenditure in computer and related activities industry. Perhaps retail expenditures on R&D were outsourced to consulting firms in the computer services sector.

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[36] For a discussion of this issue, see Cameron (1996).

[37] Annex A shows that this concentrated pattern is replicated in the industries where U.S. firms undertake overseas R&D. Most R&D done abroad by U.S. firms is concentrated in chemicals, transport equipment and computer and electronic products.

[38] "Research and Development" in this case is the name of one of the component industries of the Real estate, renting and business activities service industry.

a) Evolution over time – manufacturing

R&D intensity within manufacturing has risen significantly in some countries (e.g. Finland and Sweden), as seen in Figure 17. But from Figure 15, it can be seen that there is a general downward trend in the importance of the manufacturing sector in most economies. Some countries have not followed this trend however, notably Ireland, Finland and Canada.[39]

Over 1989-1999 across the OECD there has been a decline in the proportion of total R&D done in manufacturing, as seen in Figure 16. The increased relative size[40] and research intensity[41] of the service sector played a key role in reducing the share of R&D performed in manufacturing in most countries. But, in addition, manufacturing R&D's share of GDP declined in many countries indicating that manufacturing's smaller share of the economy outweighed generally higher research intensity.[42]

But, as seen in Figure 19, the majority of R&D continues to be done in manufacturing with Finland and Sweden maintaining more than 85 per cent of research there. Less of total research is done in manufacturing in Canada than in most other countries.

b) Evolution over time – Services

Figure 20 shows a fairly continual and at times sharp increase in service sector R&D intensity in Sweden, Denmark, Australia and the U.S. (although R&D intensity dipped in the U.S. in the early 90s). This increased research intensity may have been a result from the general boom of the late 90s. Although Canada has relatively high service-sector R&D intensity, its research intensity was virtually flat from 1994 onwards resulting in Canada's research intensity moving from first in 1994 to fourth in 1999. Fifth and sixth placed countries, Ireland and Finland, were rapidly increasing their research intensity over the late 90s.

R&D intensity in services has been increasing but also services have become a more important part of most developed economies, as seen in Figure 18 (but the rate of increase in the role of services has stagnated in Canada over the 90s). As a result, service-sector R&D is becoming a larger part of total R&D although still an order of magnitude lower than the importance of manufacturing R&D, as seen in Figure 19. In the U.S. and Australia, following a dip in the early part of the 90s, there was a sharp rise in the share

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[39] The increase in Canada may reflect increased investment in motor vehicles discussed later.
[40] Which increased in all countries except Ireland.
[41] Which increased in all countries except the U.K. (Figure 20)
[42] A decline in manufacturing R&D as a proportion of GDP happened in France, Germany, the Netherlands, the U.K. and the U.S. If the share of manufacturing in GDP had remained the same, this decline would still have taken place in the Netherlands and the U.S. because of a decline in research intensity (the only two countries where this happened). The decline in the size of manufacturing industry would (at constant research intensity) have led, in addition, to a decline in manufacturing R&D as a share of GDP in Australia, Denmark, France, Germany, Japan, Sweden and the U.K.

of research done in the service sector. The share of research done in services declined over the 90s in Canada, so that Canada moved from first to fourth in terms of its share.

Canada-U.S. Sector level differences

This section serves as an introduction to the data on Canadian and U.S. R&D expenditures. It also serves to highlight the potential difficulties in aggregating data. The results of a decomposition undertaken at a more detailed industry level (next section) are contrasted with the implications from using sector-level data.

Canada-U.S. comparisons are given in Table 1 and Table 2 below. Canadian aggregate R&D intensity in the business sector is 1.06 per cent whereas it is 1.94 per cent in the U.S., a gap of 0.88 percentage points.

Table 1: Basic Aggregate Data for Canada, 1999

Industry	Value Added	Share in GDP	R&D Expenditure	Share of R&D in Total R&D	Own R&D Intensity
Canadian GDP	909691	100.00%			
Agriculture[43]	22591	2.48%	0		
Mining And Quarrying	34468	3.79%	0		
Total Manufacturing	179704	19.75%	6558	68.02%	3.65%
Utilities[44]	26593	2.92%	185	1.92%	0.70%
Construction	46225	5.08%	26	0.27%	0.06%
Total Services	600110	65.97%	2872	29.79%	0.48%
Total Business			9641	100.00%	
Share of Total Business R&D in Total GDP			1.06%		

Note: Expenditure data in millions of Canadian dollars.
Sources: The OECD R&D Expenditure by Industry Database, The OECD STAN database for Industrial Analysis

Table 2: Basic Aggregate Data on the U.S., 1999

Industry	Value Added	Share in GDP	R&D Expenditure	Share of R&D in Total R&D	Own R&D Intensity
U.S. GDP	9,313,082	100.00%			
Agriculture	127,719	1.37%	0		
Mining And Quarrying	104,147	1.12%	0		
Total Manufacturing	1,481,341	15.91%	122,565	67.91%	8.27%
Utilities	211,002	2.27%	142	0.08%	0.07%
Construction	425,414	4.57%	699	0.3%	0.16%
Total Services	6,963,459	74.77%	57,063	31.62%	0.82%
Total Business			180,469	100.00%	
Share of Total Business R&D in Total GDP			1.94%		

Note: Expenditure data in millions of U.S. dollars.
Sources: The OECD R&D Expenditure by Industry Database, The OECD STAN database for Industrial Analysis

[43] Abbreviation of agriculture, hunting, forestry and fishing.
[44] Abbreviation of electricity, gas and water supply.

Differences in the composition of the economies can be seen by looking at the contribution of each sector to GDP, given in the third column. Agriculture, construction and mining are more important in Canada, but they remain a relatively small part of GDP. Manufacturing is also more important in Canada. The service sector is relatively small in Canada compared to the U.S, although it constitutes around two-thirds of the economy.

As can be seen from the data, R&D intensity in Canada is lower than the U.S. in both manufacturing and services. There is higher research intensity in Canada in the utilities sector, but this sector only accounts for 3 per cent of GDP. Even though the R&D intensity of services is substantially lower than manufacturing, a fair amount of R&D is done in services because of the larger size of the sector—about 30 per cent in both countries.

The impact of differences in the aggregate sectors of the economy on the overall research intensity, i.e. the impact of the different sizes of the service sector, manufacturing, etc., is examined in Table 3. Lower research intensity in Canadian sectors (which aggregate industries) explains 1.05 percentage points of the 0.88 percentage point gap. Most of the intensity effect comes from manufacturing but *ex ante* the larger size of this sector in Canada contributes positively to aggregate R&D intensity. At this level of aggregation the structure of the Canadian economy contributes positively to aggregate R&D intensity because of the larger size of the manufacturing sector, which has higher research intensity. But, as demonstrated in the next section, results at this level of aggregation can be misinterpreted because low research intensity in manufacturing can be explained by the structure of the manufacturing sector rather than by low research intensities within all manufacturing industries.[45]

Table 3: Decomposition of aggregate sector differences

	Canada		U.S.			
	Share in GDP	R&D intensity	Share in GDP	R&D Intensity	Intensity effect	Structure effect
Agriculture	2.48%	0.00%	1.37%	0.00%	0.00%	0.00%
Utilities	2.92%	0.70%	2.27%	0.07%	0.02%	0.00%
Mining	3.79%	0.00%	1.12%	0.00%	0.00%	0.00%
Constr'n	5.08%	0.06%	4.57%	0.16%	-0.01%	0.00%
Manufacturing	19.75%	3.65%	15.91%	8.27%	-0.82%	0.23%
Services	65.97%	0.48%	74.77%	0.82%	-0.24%	-0.06%
	100.00%		100.00%		-1.05%	0.18%
				Canada-US. Difference in aggregate R&D intensity		-0.88%

Sources: Underlying data from the OECD R&D Expenditure by Industry Database, The OECD STAN database for Industrial Analysis

The difficulty of using the Bennet decomposition is clear in Table 3 because two sectors (agriculture and mining) undertake no research. To try to shed light on this issue,

[45] It should also be noted that aggregation of firms to an industry may also hide important details. Obtaining firm-level data is, however, difficult.

aggregate Canadian R&D intensity will be calculated first with the U.S. sector structure and then U.S. sector research intensity.

a) Matching U.S. Sector research intensity

Table 4 shows the impact of applying U.S. research intensity to the Canadian sectors. R&D intensity is higher in almost all sectors in the U.S. Canadian R&D intensity is higher only in the utilities sector but higher implied R&D from adopting U.S. research intensity in other sectors outweighs the lower R&D induced in this sector. Overall increase in Canadian R&D from adopting U.S. research intensity is around C$10bn and the aggregate R&D intensity would more than double from around 1 per cent to 2.19 per cent of GDP, a research intensity higher than the U.S. level of 1.97 per cent, principally because the manufacturing sector is bigger in Canada.

The contribution of changed research intensity in each sector is seen in the last column of Table 4. The $8bn increase in manufacturing R&D accounts for about 80 per cent of the total increase in Canadian research. Although manufacturing only accounts for around 20 per cent of GDP, it is a very research-intensive sector in the U.S. Consequently the doubling of R&D intensity in this sector, a larger sector in Canada, accounts for around four-fifths of the total increase in expenditure from moving to U.S. research intensity.

Table 4: Adjusting Canadian Data For U.S. Research Intensity

	Canadian Value Added	U.S. R&D intensity	Implied R&D in Canada	Percentage of total R&D intensity change explained
Canadian GDP	909691			
Agriculture, Hunting, Forestry And Fishing	22591	0.00%		
Mining And Quarrying	34468	0.00%		
Total Manufacturing	179704	8.27%	14,868.57	83%
Electricity, Gas And Water Supply	26593	0.07%	17.90	-2%
Construction	46225	0.16%	75.95	0%
Total Services	600110	0.82%	4,917.70	20%
Implied Total Business R&D			19,880.12	100%
Implied Total Business R&D as a Share of Total GDP			2.19%	

Sources: Underlying data from the OECD R&D Expenditure by Industry Database, The OECD STAN database for Industrial Analysis

b) Structural Composition

Table 5 shows the impact of applying the structure of the U.S. economy to Canadian GDP. Manufacturing comprises 16 per cent of the U.S. economy but nearly 20 per cent in Canada so applying the U.S. economy's structure diminishes the importance of manufacturing, as well as the importance of agriculture and mining. Matching the U.S. structure implies more of GDP is derived from services with its lower R&D intensity.

Lowering the importance of agriculture and mining increases the share of R&D in Canada but lessening the importance of manufacturing decreases the importance of an R&D-intensive sector. The decline in manufacturing R&D is only partially offset by increased R&D in the service sector.

Matching the U.S. structure gives an aggregate R&D intensity of 0.96 per cent, a fall of 0.1 p.p. This result suggests that matching the U.S. structure would not help to increase R&D intensity.

Table 5: Applying The Structure Of The U.S. Economy To The Canadian Case

	U.S. Value Added Shares	Implied value added in Canada given Canadian GDP	Canadian R&D Intensity	Implied R&D in Canada
Grand Total	*100.00%*	909,691		
Agriculture, Hunting, Forestry And Fishing	1.37%	12,475		
Mining And Quarrying	1.12%	10,173		
Total Manufacturing	15.91%	144,696	3.65%	5,280.35
Electricity, Gas And Water Supply	2.27%	20,610	0.70%	143.46
Construction	4.57%	41,554	0.06%	23.73
Total Services	74.77%	680,183	0.48%	3,254.98
Implied Total Business R&D				8,702.52
Share of Implied Total Business R&D in Total R&D				0.96%

Sources: Underlying data from the OECD R&D Expenditure by Industry Database, The OECD STAN database for Industrial Analysis

Adopting the U.S. structure lowers aggregate R&D intensity from 1.06 per cent to 0.96 per cent—a structure effect of 0.1 percentage points—compared to U.S. aggregate R&D intensity of 1.94 per cent. The difference from 0.96 per cent to 1.94 per cent—0.98 p.p.—is a research intensity effect. On the other hand, adopting U.S. research intensity leads to an increase in intensity from 1.06 per cent to 2.19 per cent—an intensity effect of 1.13 per cent—which implies a structure effect of 0.25. Averaging over these changes, the intensity effect is -1.06 per cent and the structure effect is 0.18 per cent, the same as the Bennet decomposition.[46]

An alternative method of comparison is to assume that the share of the economy in Canada of those sectors that undertake no research (agriculture and mining and quarrying) is reduced from the Canadian level of 6.27 per cent to the U.S. level of 2.49 per cent. This change of 3.78 per cent is then evenly distributed to the other sectors of the economy. The R&D intensity of the R&D-active sectors in Canada was 1.13 per cent in 1999. Adding another 3.78 per cent of the economy with a research intensity of 1.13

[46] This decomposition is motivated by Shorrocks (1999), which first changes all the value added shares to get the structure effect and then changes the research intensity effect. The order of these changes is then reversed and the average of the effects is taken. This process is a more aggregated version of the Bennet decomposition that goes industry by industry.

would yield an additional $389m of R&D, leading to aggregate R&D increasing from 1.06 per cent to 1.10 per cent, not an enormous change. Aggregate R&D increases because freed-up resources now flow into manufacturing as well as into services.

A conclusion of this section is that the broad structure of the economy—the proportion of the economy that is either services, manufacturing or resources—is not an important explanatory factor to account for the low aggregate R&D performance. Based on this analysis, we discard the suggestion that the higher proportion of the Canadian economy based on natural resources can play a role in accounting for low aggregate R&D intensity in Canada. Applying U.S. research intensity, particularly in manufacturing, to Canada would more than explain the low aggregate R&D intensity.

The answer for low Canadian R&D intensity is to be found within the manufacturing and services sectors and the structure of the economy within manufacturing and within services may still play a role.

Industry level

This section initially discusses the raw data (and data problems) on R&D intensity for component industries of manufacturing and then services. The impact of this composition on aggregate R&D intensity is then examined. Difficulties with U.S. data on R&D in services inhibit the ability to examine the effect of individual service industries on aggregate R&D intensity.

a) Manufacturing

Data issues

In Canada, no data is available on value added in the 'Medical, precision and optical instruments, watches and clocks' industry. Such data is available in the U.S. and the data show that this industry is very research intensive with a R&D expenditures to value-added ratio of about 34 per cent. The U.S. value-added of this sector is thus added to the U.S. radio, television and communication equipment sector. The impact of this change is to increase own research intensity in this industry in the U.S. from 14.4 per cent to 20.6 per cent, compared to the Canadian level of 27.9 per cent.

Description

Statistics for the manufacturing sector are given for Canada and the U.S. in Table 6 and more time-series data for the research-intensive industries are given in Figure 21-Figure 25. In Table 6, industries are ranked according to research intensity in Canada. It is clear from the last line in the table that total manufacturing represents a smaller share of the economy in the U.S., but its research intensity is much higher. It is also clear that the ranking of research intensity in the U.S. is not completely reflected in Canada (particularly for motor vehicles).

Research intensity is much higher in some Canadian sectors, such as office and computer machinery, in pharmaceuticals, and in radio, television and communication equipment.[47] But these industries are a smaller share of GDP in Canada. On the other hand, there is a noticeable lag in R&D intensity in the motor vehicles sector and this sector is a relatively large share of value added in Canadian manufacturing.

Canadian research intensity is low in some industries that constitute a large share of Canadian GDP and a larger share of GDP than in the U.S., such as wood products and paper, and motor vehicles. However, there is a different story behind each of these cases. The first industry—wood products and paper—seems to be a low R&D-intensity industry in general whereas the motor vehicles industry is research-intensive in the U.S., as well as in many other OECD countries, but is not so in Canada.

Of the five industries that are very research intensive across countries, Canada lags in research intensity in two of these—motor vehicles and other transport equipment—and the other three sectors form a smaller part of GDP in Canada but have higher research intensity. This rough explanation of the R&D shortfall in manufacturing is confirmed by more formal decomposition analysis later in this section.

Table 6: Statistics on manufacturing in Canada and the U.S.

	Canada			U.S.		
	Share of R&D	Research intensity	Share of GDP	Share of R&D	Research intensity	Share of GDP
Office+comp.eq.	4.89%	53.63%	0.10%	5.21%	25.80%	0.39%
Radio, tel. and com. eq.	28.93%	27.87%	1.10%	20.63%	20.54%	1.95%
Pharmaceuticals	6.49%	27.51%	0.25%	6.82%	20.92%	0.63%
Other trans eq.	11.95%	14.48%	0.88%	8.75%	24.25%	0.70%
Elec machinery	1.14%	3.63%	0.33%	2.34%	10.86%	0.42%
M&E n.e.c.	2.48%	2.09%	1.26%	3.51%	5.50%	1.24%
Ref petr, plast+chem.	3.39%	1.63%	2.21%	5.83%	5.33%	2.12%
Basic metals	1.40%	1.28%	1.15%	0.26%	0.93%	0.54%
Textiles	0.71%	1.06%	0.71%	0.19%	0.64%	0.57%
Fab'd met prods	1.20%	1.03%	1.23%	0.94%	1.59%	1.15%
Furniture	0.59%	0.76%	0.82%	0.48%	1.58%	0.59%
Motor vehicles	2.03%	0.75%	2.86%	10.13%	15.30%	1.28%
Food + beverages	1.17%	0.55%	2.27%	0.85%	0.98%	1.68%
Wood and paper	1.53%	0.39%	4.13%	1.64%	1.44%	2.21%
Other min prod	0.13%	0.29%	0.46%	0.34%	1.49%	0.44%
Total manufacturing	68.02%	3.65%	19.75%	67.91%	8.27%	15.91%

Sources: Underlying data from the OECD R&D Expenditure by Industry Database, The OECD STAN database for Industrial Analysis

[47] As seen in Figure 21-Figure 25, R&D intensity has been increasing in industries such as pharmaceuticals, a fact masked by its smaller share of GDP. This increasing intensity in pharmaceutical R&D is consistent with the findings of Pazderka (1999).

The data in Figure 21 through Figure 25 show the recent evolution of five research-intensive industries. As discussed previously, some Canadian industries have high R&D intensity.

It is noticeable that research intensity in pharmaceuticals increased markedly in Canada but the importance of the industry in terms of its share of GDP was roughly constant. The opposite held in the U.S.: research intensity was constant but its share of total value added increased. As a result, pharmaceutical R&D as a proportion of GDP increased in both countries. There was a sharp decline in research intensity in the other transport equipment industry in the U.S. Such a decline is not replicated in Canada and its share of GDP has actually increased in Canada. These changes may have been driven by the decline of defense expenditures in the U.S. over the 90s. The only significant increase in the importance of a Canadian industry that is supposed to be R&D intensive was the motor vehicles industry and this industry has extremely low R&D intensity in Canada compared to that in the U.S.

b) Service Sector

Data issues

Some data on R&D expenditures in services appears to be missing: U.S. R&D expenditures given for component industries in services add up to around 80 per cent of the value of total expenditures given for the entire sector. This missing expenditure has not been allocated to any service industry and therefore the R&D intensity of the given industries may be understated in the U.S.

Description

Data on research undertaken in the service sector is given in Table 7. Many service sector industries undertake no research according to these data.[48] Research intensity in the wholesale and retail sector is noticeably lower in Canada than in the U.S. This sector is also larger in the U.S., accounting for nearly 17 per cent of GDP, almost double the relative size of this sector in the Canadian economy. Research intensity in Canada and the U.S. is not dissimilar in the real estate, renting and business activities sector.

c) Composition

The impact of industrial structure and R&D intensity differences can be seen in Table 8. Because the sum of industry's R&D expenditures does not add up to the total in the U.S. service sector, the service sector is considered as one industry in this decomposition. High own research intensities are concentrated in a few industries. Industries are ranked in this table according to Canadian research intensities. Those research-intensive industries do not constitute a large part of GDP. Various services industries figure much more prominently.

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[48] For example, the hotels and restaurants industry in Canada produced C$22bn of value added in 1999 but undertook no research.

Table 7: Data on service sector

	Canada			U.S.		
	Share of aggregate R&D	Own R&D Intensity	Share in GDP	Share of aggregate R&D	Own R&D Intensity	Share in GDP
Com'y, social and personal serv.	0.00%	0.00%	19.77%	0.00%	0.00%	21.17%
Hotels and restaurants	0.00%	0.00%	2.43%	0.00%	0.00%	0.86%
Transport and storage	0.21%	0.05%	4.28%	0.26%	0.15%	3.24%
Financial intermediation	1.97%	0.30%	6.97%	0.87%	0.21%	8.04%
Post and telecoms.	0.92%	0.35%	2.79%	0.87%	0.49%	3.43%
Wholesale and retail	7.41%	0.69%	11.31%	11.06%	1.25%	17.08%
Real estate, renting and business activities	19.28%	1.11%	18.41%	12.15%	1.12%	20.95%
Other[49]				6.41%		
Total Services	29.79%	0.48%	65.97%	31.62%	0.82%	74.77%

Sources: Underlying data from the OECD R&D Expenditure by Industry Database, The OECD STAN database for Industrial Analysis

Of the aggregate gap of 0.88 percentage points of GDP with the U.S., 69 per cent (or 0.6 p.p.) comes from lower research intensity. Most of the lower research intensity (about 90 per cent) is driven by low intensity in the services (0.24 p.p.) and motor vehicles (0.30 p.p.) industries. The raw data in Table 7 suggests that the shortfall in services R&D is caused by the wholesale and retail trade industry.[50] These results suggest that Canada's lower aggregate R&D intensity does not reflect lower R&D intensity across all Canadian industries, but is instead caused by very low research intensities in a few industries.[51]

For those industries that are more research intensive, the structure effect is more important: these industries constitute a smaller part of the overall Canadian economy

[49] Data are given for component service industries and for total services. The data on component industries add up to 79.74 per cent of total services.

[50] An alternative methodology was applied where the difference between total service R&D and its component industries was allocated to increase nominal R&D expenditures proportionately in the U.S. data. This 25.4 per cent across-the-board increase in service industries' R&D expenditure led, for example, to wholesale and retail trade industry having an R&D intensity of 1.57 per cent and real estate, renting and business activities industry having an R&D intensity of 1.41 per cent. The total intensity effect declined from -0.6 per cent to -0.56 per cent and the total structure effect increased from -0.28 per cent to -0.32 per cent. The principal components of the service industries' role in explaining aggregate R&D composition were: the intensity effect of the wholesale and retail industry at -0.12 per cent and -0.06 for real estate; a structure effect of –0.07 per cent for wholesale and retail and –0.03 per cent for real estate. Consequently, under this methodology, the predominant factor explaining the service industry's R&D intensity remained the wholesale and retail trade industry with possibly a non-trivial role played by the real estate, renting and business activities industry.

[51] It is difficult to know, however, whether R&D undertaken in a firm is allocated to the same industry in different countries. For example, might the R&D of a firm be allocated to computer manufacturing in one country, but the activities of the same firm in another country be allocated to the wholesale and retail industry.

compared to the U.S. In other words the higher research intensity in these industries compared to the U.S. is outweighed by their smaller relative size.

Although not highly research intensive, a group of three industries that undertake almost 7 per cent of total R&D in Canada[52] have lower research intensities in Canada compared to the U.S. even though they are of roughly the same proportion of GDP (i.e. they have no structure effect). The cumulative effect of lower research intensities in refined petroleum, plastics and chemicals, M&E not elsewhere classified, and electrical machinery and apparatus not elsewhere classified, is a non-trivial 0.15 p.p.: this effect alone outweighs the positive impact of higher Canadian research intensity of R&D in pharmaceuticals and in radio, television and communication equipment.

The potential for differing impacts of foreign ownership are highlighted when looking at motor vehicles and services. Low R&D intensity in motor vehicles may reflect most R&D being done in the U.S. and foreign firms in Canada take advantage of the R&D done in their home country. The middle panel of Figure 3 shows that the overall R&D-to-sales ratio for foreign-controlled manufacturing firms is lower in manufacturing than for Canadian firms.

However, as is clear from Figure 3, the picture is different in services. For total services, R&D intensity (as a percentage of sales) is higher for foreign firms in Canada than for Canadian firms. Figure 5 shows that R&D intensity was higher for foreign-controlled in many of the component service industries as well. Furthermore, R&D intensity is increasing at a more rapid pace in foreign companies. Figure 7 shows that foreign R&D intensity as a proportion of sales increased markedly in foreign-controlled firms in the wholesale and retail trade, far outstripping their Canadian counterparts.

[52] Compared to almost 12 per cent in the U.S.

Table 8: Structure and intensity effects

	Canada		U.S.			
	Research intensity	Share of GDP	Research intensity	Share of GDP	Intensity effect	Structure effect
Agriculture	0.00%	2.48%	0.00%	1.37%	0.00%	0.00%
Mining	0.00%	3.79%	0.00%	1.12%	0.00%	0.00%
Construction	0.06%	5.08%	0.16%	4.57%	-0.01%	0.00%
Other non-metallic mineral products	0.29%	0.46%	1.49%	0.44%	-0.01%	0.00%
Wood and paper	0.39%	4.13%	1.44%	2.21%	-0.03%	0.02%
Total services	0.48%	65.97%	0.82%	74.77%	-0.24%	-0.06%
Food products, beverages and tobacco	0.55%	2.27%	0.98%	1.68%	-0.01%	0.00%
Utilities	0.70%	2.92%	0.07%	2.27%	0.02%	0.00%
Motor vehicles	0.75%	2.86%	15.30%	1.28%	-0.30%	0.13%
Furniture; manufacturing n.e.c.	0.76%	0.82%	1.58%	0.59%	-0.01%	0.00%
Fabricated metal products, exc. M&E	1.03%	1.23%	1.59%	1.15%	-0.01%	0.00%
Textiles, textile products, leather and footwear	1.06%	0.71%	0.64%	0.57%	0.00%	0.00%
Basic metals	1.28%	1.15%	0.93%	0.54%	0.00%	0.01%
Refined petroleum, plastics and chemicals	1.63%	2.21%	5.33%	2.12%	-0.08%	0.00%
M&E n.e.c.	2.09%	1.26%	5.50%	1.24%	-0.04%	0.00%
Electrical machinery and apparatus, n.e.c.	3.63%	0.33%	10.86%	0.42%	-0.03%	-0.01%
Other transport equipment	14.48%	0.88%	24.25%	0.70%	-0.08%	0.03%
Pharmaceuticals	27.51%	0.25%	20.92%	0.63%	0.03%	-0.09%
Radio, tel. and com. eq.	27.87%	1.10%	20.54%	1.95%	0.11%	-0.20%
Office, accounting and computing machinery	53.63%	0.10%	25.80%	0.39%	0.07%	-0.12%
		100%		100%	-0.60%	-0.28%
Total gap accounted for between R&D intensities in Canada and the U.S.						-0.88%

Sources: Underlying data from the OECD R&D Expenditure by Industry Database, The OECD STAN database for Industrial Analysis

d) Cross-country comparisons

The previous discussion suggests that aggregate R&D intensity may mask R&D performance by industries within a country. Table 9, in the first two columns, shows fifteen OECD countries ranked according to their aggregate R&D intensity.[53] The columns that follow give the R&D intensity within each of the high-tech industries and the ranking of a country in each industry. For example, Canada ranks eleventh in overall R&D intensity in this table, first in office, machinery and computer equipment but fourteenth in motor vehicles. Because the R&D intensities in some industries can be somewhat volatile, these rankings by industry should be treated with caution.[54]

The performance across countries can be quite different. Sweden ranks fairly highly in all five industries, and its overall rank is first. On the other hand South Korea ranks in the bottom third in these five industries but its overall ranking is fifth. South Korea concentrates much of its R&D in motor vehicles and communication equipment (combined these were just over 50 per cent of total research in South Korea compared to around 40 per cent in Sweden and around 30 per cent in Canada). These data highlight that Table 9 does not capture industry size differences across countries. As such, this table only captures where areas of strength in R&D may exist.

Table 10 shows some summary statistics of Table 9. The fourth column takes the average of the rankings across the five industries in Table 9: on average Canada has a ranking of 6.6. The fifth column gives an ordinal measure of the second column. Hence Canada's average ranking of 6.6 implies that it has the fifth highest average ranking.

One aspect of Canada's R&D weakness is shown in the last two columns. The variance of Canada's ranking in R&D is the fourth highest. Canada has four industries in the top six but then motor vehicles ranks fourteenth. A similar story exists in the U.K., which has the highest dispersion in ranking. Germany and Sweden have fairly consistent strength in all five industries.[55] Spain, Italy and South Korea have fairly consistent poor ranking in all five industries.

The effect of the motor vehicle industry is shown in Table 11, which shows a larger impact on Canada's rankings than most other countries. Only looking at four of the research-intensive industries moves Canada's average ranking from fifth to third: Canada has the third highest ranking for research intensity in these four industries. A similar increase in ranking is obtained in Belgium, Finland and Denmark. Going in the opposite direction, Japan drops from seventh to tenth (displaying the only larger absolute change than that of Canada) and the U.S. goes from fourth to sixth.

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[53] Some of this data is shown graphically in Figure 26.

[54] Ranking in other transport equipment is particularly volatile, probably reflecting volatility of value added rather than in R&D expenditure.

[55] Although the data on pharmaceuticals R&D is missing for Germany.

The effect of excluding motor vehicles has an even greater effect on the average dispersion of research intensities where the decline in variance is by far the greatest for Canada. With five industries Canada has the fourth highest variance but without motor vehicles Canada has the fifth lowest, implying that Canada has consistently high research intensities outside of motor vehicles. Excluding motor vehicles increases the variance in the U.K.'s research intensities, but it already had the highest variance anyhow. The variance shows a relatively large decline in South Korea to a consistently low ranking across four industries.

Table 9: R&D intensities (as a percentage of own value added) of high-tech industries), latest available years[56]

	Business R&D as percentage of GDP, 1999	Pharmaceuticals	Rank	Office, machinery and computer	Rank	Radio, telephone and communication equipment	Rank	Motor vehicles	Rank	Other transport equipment	Rank
1 Sweden	2.84	48.0	3	13.9	9	64.8	1	24.6	1	19.9	5
2 Finland	2.19	57.1	1	22.0	4	25.6	7	3.6	12	3.7	12
3 Japan	2.08	21.5	9	37.7	2	17.8	13	13.1	4	10.7	9
4 U.S.	1.99	20.9	10	25.8	3	20.9	10	15.3	3	24.3	3
5 Korea	1.76	3.9	14	7	13	17.9	12	8.9	10	1.1	15
6 Germany	1.7	-	-	16.7	6	36.2	3	19.2	2	28.1	2
7 Belgium	1.4	25.9	7	14.9	8	35.2	4	4.0	11	7.1	11
8 France	1.38	27.6	5	13.3	10	34.1	5	13.1	4	28.8	1
9 Denmark	1.32	34.9	4	18.3	5	15.0	14	0.0	15	10.1	10
10 U.K.	1.25	54.2	2	3.1	14	13.7	15	10.3	8	22.1	4
11 Canada	1.02	27.5	6	53.6	1	27.9	6	0.79	14	14.5	6
12 Norway	0.95	23.1	8	16.5	7	54.5	2	10.4	7	1.8	14
13 Ireland	0.88	7.1	13	2.3	15	24.1	8	12	6	2.7	13
14 Italy	0.51	10.7	11	9.3	11	22.3	9	9.7	9	13.7	7
15 Spain	0.46	10.1	12	7.5	12	19.1	11	2.6	13	13.0	8

Source: OECD (2002), Canadian and U.S. data updated to reflect results in this paper

[56] Years range from 1997 to 2000.

Table 10: Summary statistics on rankings in high-tech industries

	Business R&D/GDP	Rank according to business R&D/GDP	Average Ranking	Ranking of average ranking	Variance of ranking in the five industries	Rank according to most vaiance
Sweden	2.8	1	3.8	2	11.2	9
Finland	2.2	2	7.2	6	23.7	3
Japan	2.1	3	7.4	7	19.3	5
U.S.	2.0	4	5.8	4	14.7	7
Korea	1.8	5	12.8	15	3.7	12
Germany	1.7	6	3.25	1	3.6	14
Belgium	1.4	7	8.2	9	8.7	11
France	1.4	8	5.0	3	10.5	10
Denmark	1.3	9	9.6	12	25.3	2
U.K.	1.3	10	8.6	10	33.8	1
Canada	1.0	11	6.6	5	21.8	4
Norway	1.0	12	7.6	8	18.3	6
Ireland	0.9	13	11.0	13	14.5	8
Italy	0.5	14	9.4	11	2.8	15
Spain	0.5	15	11.2	14	3.7	12

Source: OECD (2002), Canadian and U.S. data updated to reflect results in this paper

Table 11: The Effect on Rankings of Excluding Motor Vehicles

		Including Motor Vehicles				Excluding Motor Vehicles			
	Rank according to business R&D/GDP	Average Ranking	Ranking of average ranking	Variance of ranking	Rank according to moat variance	Average Ranking ex. Motor Vehicles	Ranking of average ranking	Variance of ranking	Rank according to moat variance
Sweden	1	3.8	2	11.2	9	4.5	2	11.7	8
Finland	2	7.2	6	23.7	3	6.0	5	22.0	3
Japan	3	7.4	7	19.3	5	8.3	10	20.9	5
U.S.	4	5.8	4	14.7	7	6.5	6	16.3	6
Korea	5	12.8	15	3.7	12	13.5	15	1.7	15
Germany	6	3.3	1	3.6	14	3.7	1	4.3	12
Belgium	7	8.2	9	8.7	11	7.5	7	8.3	10
France	8	5.0	3	10.5	10	5.3	4	13.6	7
Denmark	9	9.6	12	25.3	2	8.3	10	21.6	4
U.K.	10	8.6	10	33.8	1	8.8	11	44.9	1
Canada	11	6.6	5	21.8	4	4.8	3	6.3	11
Norway	12	7.6	8	18.3	6	7.8	8	24.3	2
Ireland	13	11.0	13	14.5	8	12.3	14	8.9	9
Italy	14	9.4	11	2.8	15	9.5	12	3.7	13
Spain	15	11.2	14	3.7	12	10.8	13	3.6	14

Source: OECD (2002), Canadian and U.S. data updated to reflect results in this paper

e) Other Research

Whewell(1999) examines differences in R&D performance between Canada and the U.S. Her data relates to those firms that undertake R&D, and is therefore not representative of Canada-U.S. differences as a whole.[57] Nevertheless, her results are quite similar: she finds that industry structure accounts for a bit less than a third of Canada-U.S. differences in her sample; R&D intensities and differences in firm size account for the rest.

Research undertaken by Jonathan Eaton et al. (1998) found some similar evidence for the OECD. They try to explain differences between all OECD countries' research intensity and the OECD average in 1988-90. The authors only look at manufacturing industries and report only aggregate results.

In most countries research intensity differences explain the gap between a country's research intensity and the OECD average whereas the composition effect is relatively unimportant: "major research economies tend to do more research across industries".[58] The authors note that the lack of importance of the composition and interaction effects implies that "understanding why some countries emerge as research centres requires knowing why they do more research overall, not why they are attractive to high-tech sectors."[59] If composition effects were important then one would have to examine what factors made certain countries more attractive as locations for R&D activity.

On the other hand, for Canada they found that the intensity effect was only slightly more important than the structure effect. The results are consistent with the results of this paper: a large portion of the intensity effect in Canada comes from services and abstracting from the service intensity effect in Table 8 would result in roughly equal intensity and structure effects found in Eaton et al.(1998).

Koopmann and Münnich (1999) found that the structural and intensity effects (measured in terms of employment) contributed roughly equally in explaining Canada's deviation from the G7 mean for manufacturing R&D in 1995. In most countries they also found that R&D intensity was the predominant explanatory factor.

These results suggest that the level of research intensity within industries usually accounts for differences in research intensity across countries.[60] But, according to the results in this paper, the research intensity effect between Canada and the U.S. is explained almost entirely by motor vehicles and services (and, more specifically, wholesale and retail trade, it seems). It is not clear if digging down into the data from the other research cited above would result in the same story: that the intensity effect is located in a few industries in other countries. But, taking the other research at face value

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[57] Sample statistics for quoted in Whewell(1999) do not match aggregate data available.
[58] pp. 411, Eaton et al. (1998).
[59] pp. 411, Eaton et al. (1998).
[60] A similar result was found in a pairwise comparison of R&D intensity trends between the U.K. and the U.S. over the 1980s and 1990s. Griffith and Harrison (2003) found that "the U.K.'s poor business R&D performance relative to the U.S. was due to weak within-sector growth in R&D intensity rather than a shift in output towards low-R&D-intensity sectors."

as well as the results in this paper, it seems that there is an important structure effect in Canada. Therefore one has to find explanations for why some of the highly R&D intensive industries are relatively smaller in Canada.

5. Conclusion

The goal of this paper was to account for business R&D intensity differences between Canada and the U.S. The traditional arguments to explain low aggregate R&D intensity in Canada are a) a large natural resource sector; b) a large degree of foreign ownership and c) the effect of firm size. Cursory analysis of data across OECD countries suggested that intensity and composition effects within research-intensive industries are important to explaining aggregate R&D performance.

Composition analysis showed that low aggregate R&D intensity in Canada relative to the U.S. could generally be accounted for by:

1. Low R&D intensity in the service sector (and the wholesale and retail trade industry in particular) and the motor vehicles industry;

2. The relatively smaller share of research-intensive industries (except for motor vehicles) in the economy.

Research intensity in some of the research-intensive industries in Canada is higher than in the U.S. and amongst the highest in the world in some of them. So low aggregate R&D intensity in Canada does not reflect low R&D intensity within all industries.

Finding economic explanations for the pattern of R&D intensities in Canada is more complicated. Looking at the distribution of research intensities within manufacturing, it is clear that R&D intensity in motor vehicles in Canada is particularly low and this factor is mostly responsible for the lower average research intensity in manufacturing. Research intensity is higher than in the U.S. in many of the industries that are research intensive: office and computing machines, pharmaceuticals and in radio, television and communication equipment. But these latter sectors are a larger share of the U.S. economy.

Based on this analysis, we conclude that the aggregate sectoral composition of the Canadian economy is not important in explaining the shortfall in aggregate research intensity in Canada compared to the U.S. Research intensity is significantly lower in both manufacturing and services in Canada (although the more detailed structure of these sectors is important). But that Canada has a larger resource sector has no material impact on R&D intensity.

The second explanatory factor advanced to explain low aggregate R&D intensity is the high degree of foreign ownership present in Canada. But, foreign-owned firms have

much higher R&D-to-sales intensity in services and at the same time have lower intensity in motor vehicles than do Canadian firms. But these are the two industries that mostly account for weak aggregate R&D intensity in Canada. Existing studies on the impact of foreign ownership have failed to examine the effect of detailed industry composition. That R&D as a proportion of sales in foreign pharmaceutical firms is lower than their Canadian equivalents may be irrelevant given that over three-quarters of pharmaceutical R&D is done by foreign firms: foreign firms may be increasing total R&D as a proportion of GDP even if they lower R&D intensity within an industry.

This paper does not provide any direct evidence on the impact of firm size on aggregate R&D intensity. However, literature in other countries suggests that firm size is not an explanatory factor.

After having cast doubt on the conventional explanations, we conclude that it is likely that explanations of industries' R&D performance are specific to the microeconomic structure of each industry. A further observation based on this paper is that future research in Canada needs to carefully control for detailed industry effects. Failure to have comprehensively controlled for industry effects may have introduced biases into the results of previous research in this area.

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Annex A: R&D Investment Abroad by U.S. Firms

This Annex looks at the pattern of R&D undertaken abroad by U.S. affiliates. The investment reflects the sector-specific nature of R&D. Figure 8 shows that there has been a steady increase in the proportion of R&D that is financed from abroad in most countries.[61] This annex looks at some basic facts about outward flows from the U.S. As seen in Figure A1, two-thirds of R&D performed overseas in 2000 by U.S. companies took place in six countries: U.K., Germany, Canada, Japan, France and Sweden.[62]

Figure A1: Where U.S. foreign investment in R&D goes

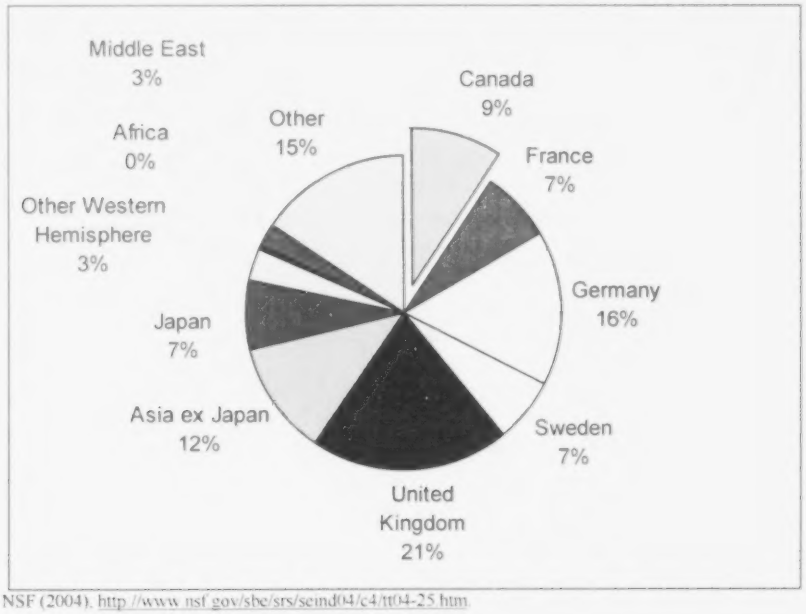

Table 4-25, NSF (2004), http://www.nsf.gov/sbe/srs/seind04/c4/tt04-25.htm

Overseas R&D activity by U.S. firms is concentrated in three industries: transport equipment, computer and electronic products, and chemicals and pharmaceuticals, as seen in Figure A2. The trends in foreign investment in R&D replicate the sector-specific nature of R&D. In 1996, Germany accounted for almost half of offshore automotive R&D and most of the investment by U.S. firms in the Netherlands was accounted for by electrical equipment. The pattern of overseas investment in research centres by the U.S. in R&D is shown in Figure A4.

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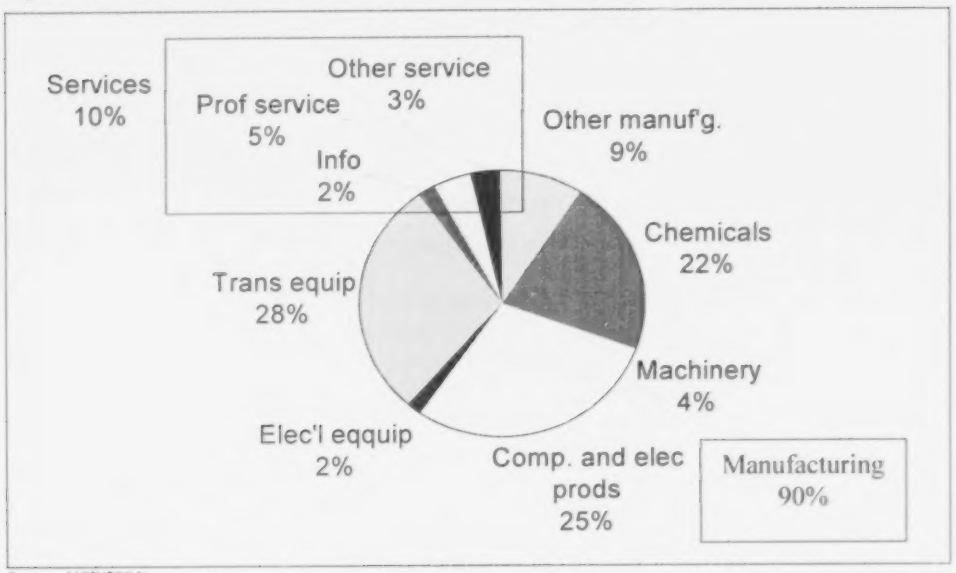
[61] Some countries have higher business R&D expenditures, so looking only at foreign-financed R&D as a percentage of domestic business R&D may give a distorted picture. But looking at the R&D financed from abroad as a percentage of GDP, the pattern is roughly similar. The U.K. is ranked first in 1999 and Canada second, both with foreign-funded R&D at around 0.28 per cent of GDP. Sweden's rank moves from 13th to 7th.

[62] Data in the rest of the section excludes Sweden because U.S. investment in Sweden is concentrated in a few firms (e.g. GM and Ford's ownership of SAAB and Volvo cars respectively) and hence, for confidentiality reasons, the data on U.S. investment in Swedish sectors are not published.

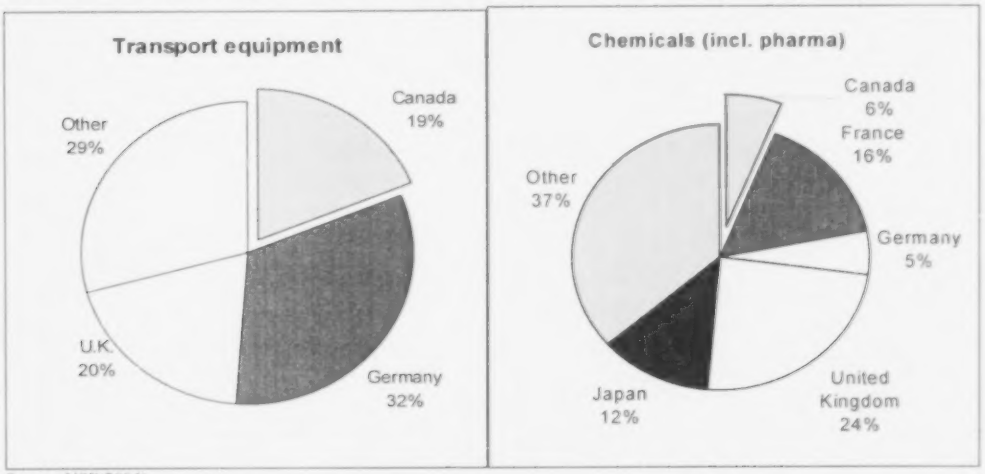
Figure A2: The concentration of U.S. investment undertaken overseas in R&D



Source: NSF(2004)

As can be seen from Figure A3, favoured destination countries for R&D in transport equipment and chemicals are few (and noting that Sweden is likely a big part of 'other' in both cases). But the pattern is more disperse for computers and electronic products. In this industry, the U.K. accounts for only 10 per cent of U.S. R&D, the highest of the big countries. Singapore, Israel, Ireland, Taiwan and South Korea combined account for 25 per cent of total overseas R&D by the U.S., and this pattern conforms to the rising importance of R&D centres in these countries.[63]

Figure A3: Foreign destinations for U.S. R&D investment in two industries



Source: NSF(2004)

[63] http://www.nsf.gov/sbe/srs/seind04/c4/tt04-26.htm.

The pattern of U.S. investment has been shifting. The share of U.S. firms' overseas R&D undertaken in Europe has decline from 75 per cent to 68 per cent over the period 1982-1996. U.S. overseas R&D has shifted from larger European countries and Canada. The target countries are Japan, Australia, Brazil and smaller European countries (Sweden and the Netherlands in particular).

Figure A4: Countries with 4 or more U.S. R&D facilities, 1997

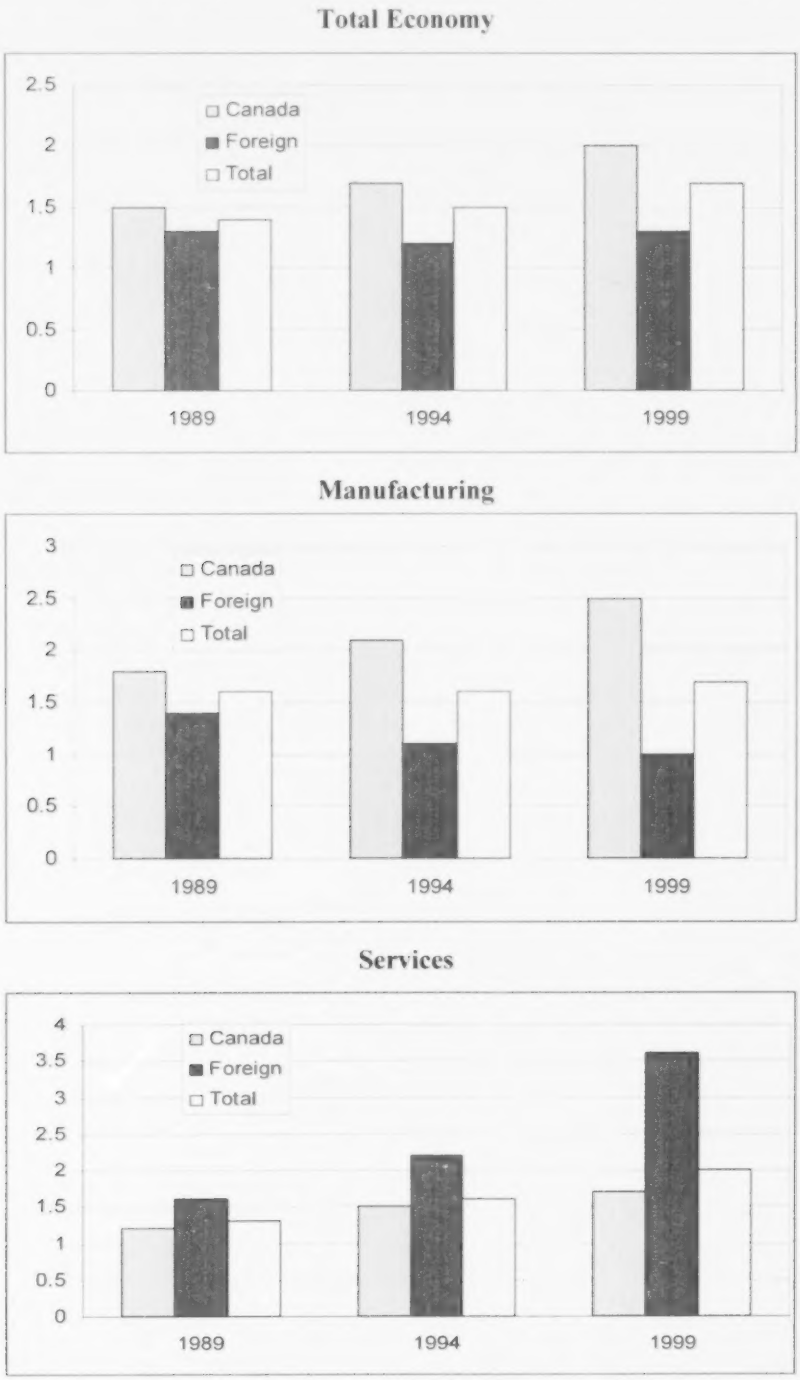
	Japan	U.K.	Canada[64]	France	Germany
1)	Chemicals, rubber (9)	Drugs & biotechnology(5) Instrumentation, medical devices (5) Computers (5)	Metals, petroleum refining (6)	Automotive(4)	Automotive(5)
2)	Drugs, biotechnology(8)	Automotive(4)	Drugs & biotechnology(4) Automotive(4)		
3)	Computers (7)				
4)	Software (4) Semiconductors (4)				
Total R&D facilities	43	27	26	16	15

Source: NSF(2004)

[64] Investment by Canadian firms in R&D performed in the U.S. amounted to U.S.$1,397m in 1996.

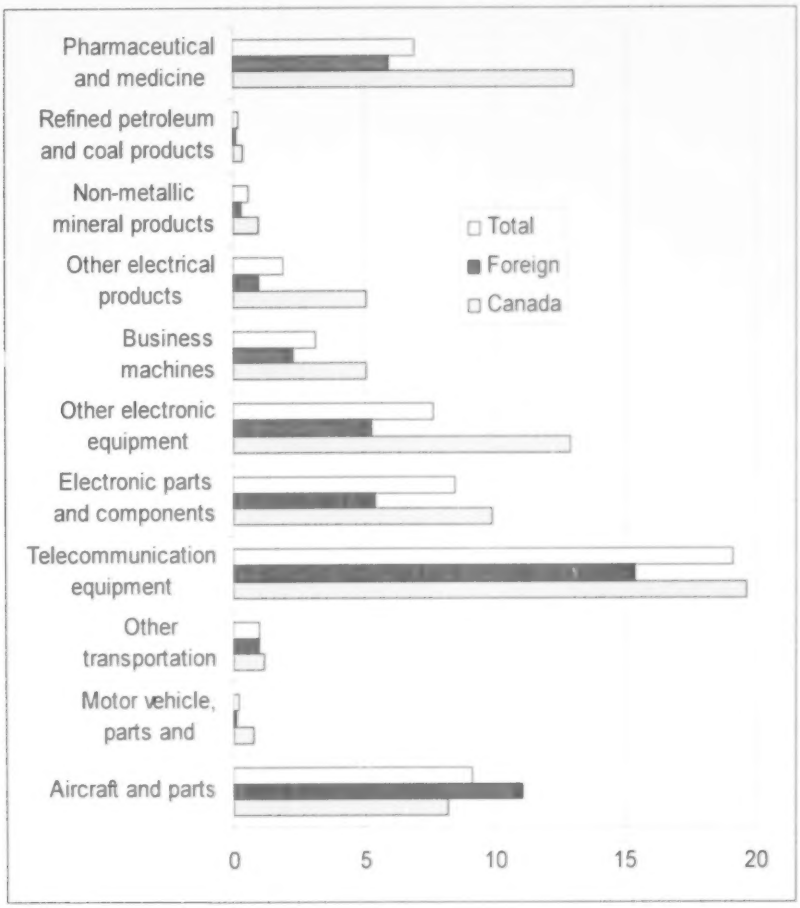
Appendix B: Graphs

Figure 3: Intramural R&D expenditures as a percent of company revenues by country of control.



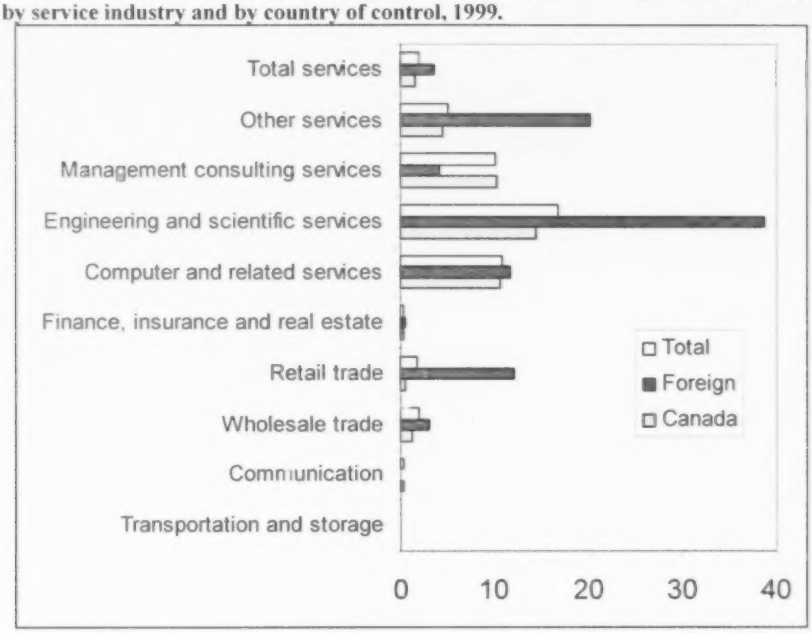
Source: Statistics Canada

Figure 4: Current intramural R&D expenditures in Canada as a percent of performing company revenues, by manufacturing industry and by country of control, 1999.



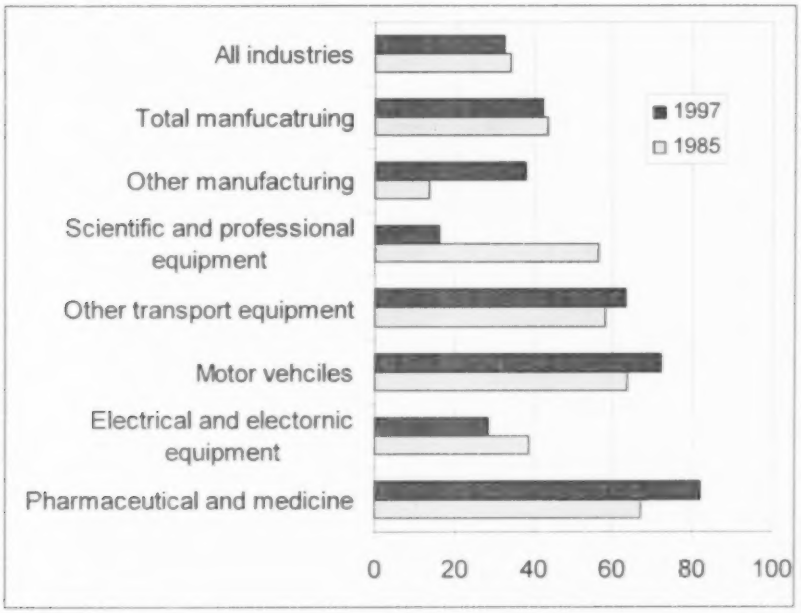
Source: Statistics Canada

Figure 5: Current intramural R&D expenditures in Canada as a percent of performing company revenues, by service industry and by country of control, 1999.



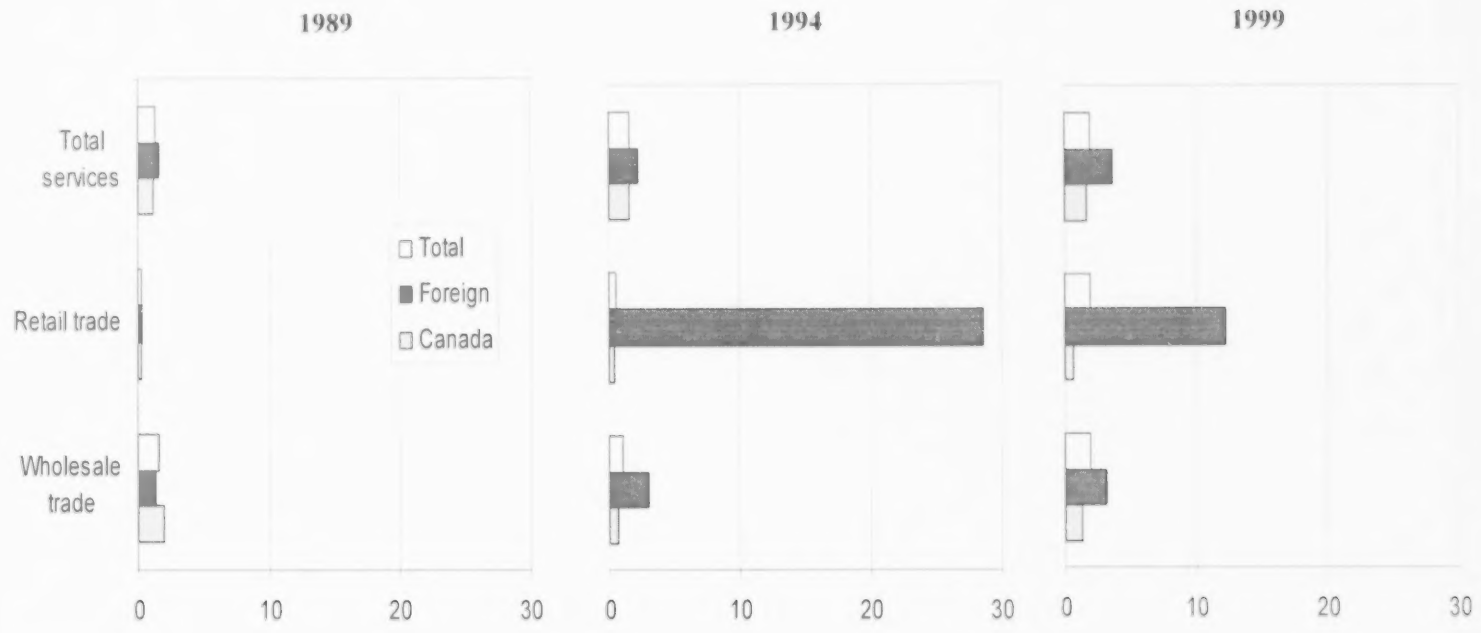
Source: Statistics Canada

Figure 6: Share of foreign-controlled firms in R&D expenditures in Canada for selected industries and aggregates



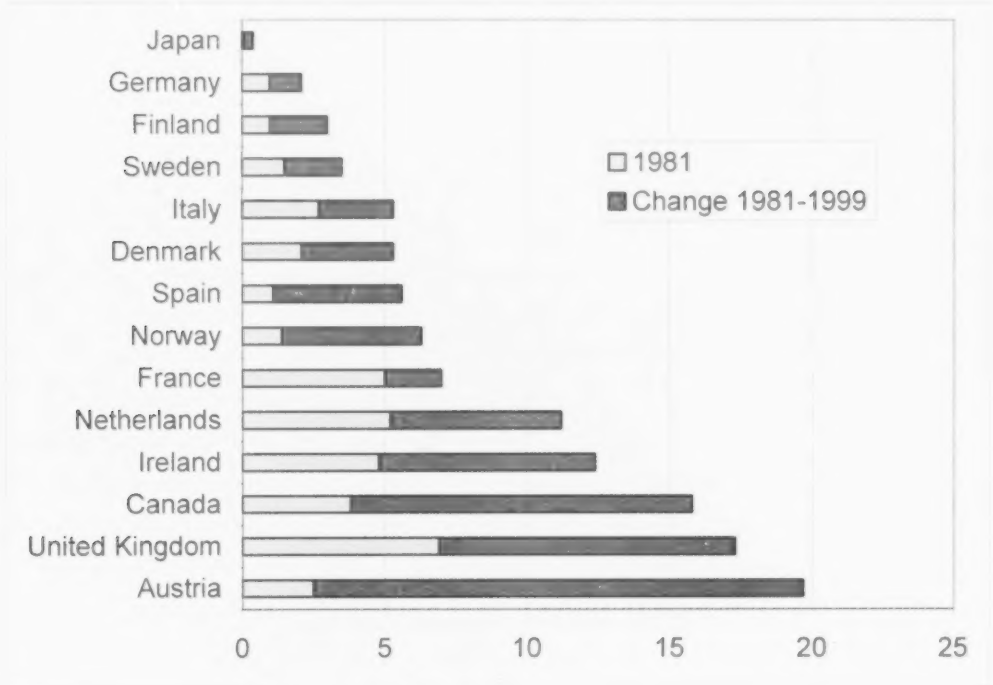
Source: Rao and Tang (2001)

Figure 7: R&D as a percentage of sales in retail and wholesale trade, and total services.



Source: Statistics Canada

Figure 8: Percentage of gross R&D financed from abroad[65]



[65] Data on foreign R&D investment by and in the U.S. is very partial and not displayed. In 2000, foreign-owned R&D spending accounted for 13 percent of the $199.5 billion in total industrial R&D expenditures in the United States, according to NSF's Survey of Industrial Research and Development (NSF(2004)). Quoted in http://www.nsf.gov/sbe/srs/seind04/c4/c4s5.htm#overview2. Some countries have higher business R&D expenditures, so looking only at foreign-financed R&D as a percentage of domestic business R&D may give a distorted picture. But looking at the R&D financed from abroad as a percentage of GDP, the pattern is roughly similar. The U.K. is ranked first in 1999 and Canada second, both with foreign-funded R&D at around 0.28 per cent of GDP. Sweden's rank moves from 13th to 7th. Note that R&D investment in the U.S. financed from abroad is excluded from this graph because of data problems.

Figure 9: R&D undertaken by foreign affiliates of U.S. firms, normalized by GDP[66]

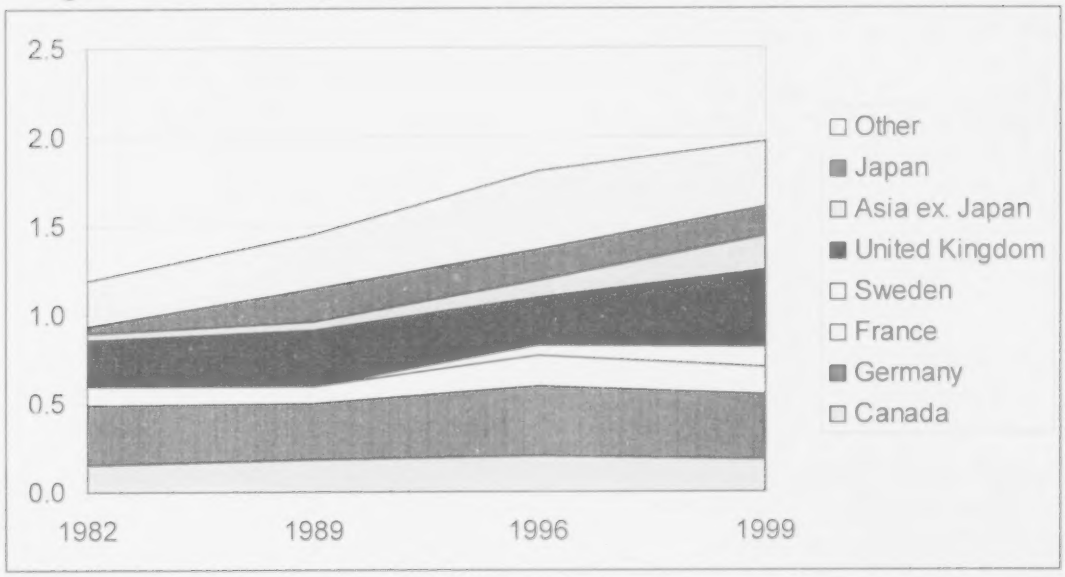
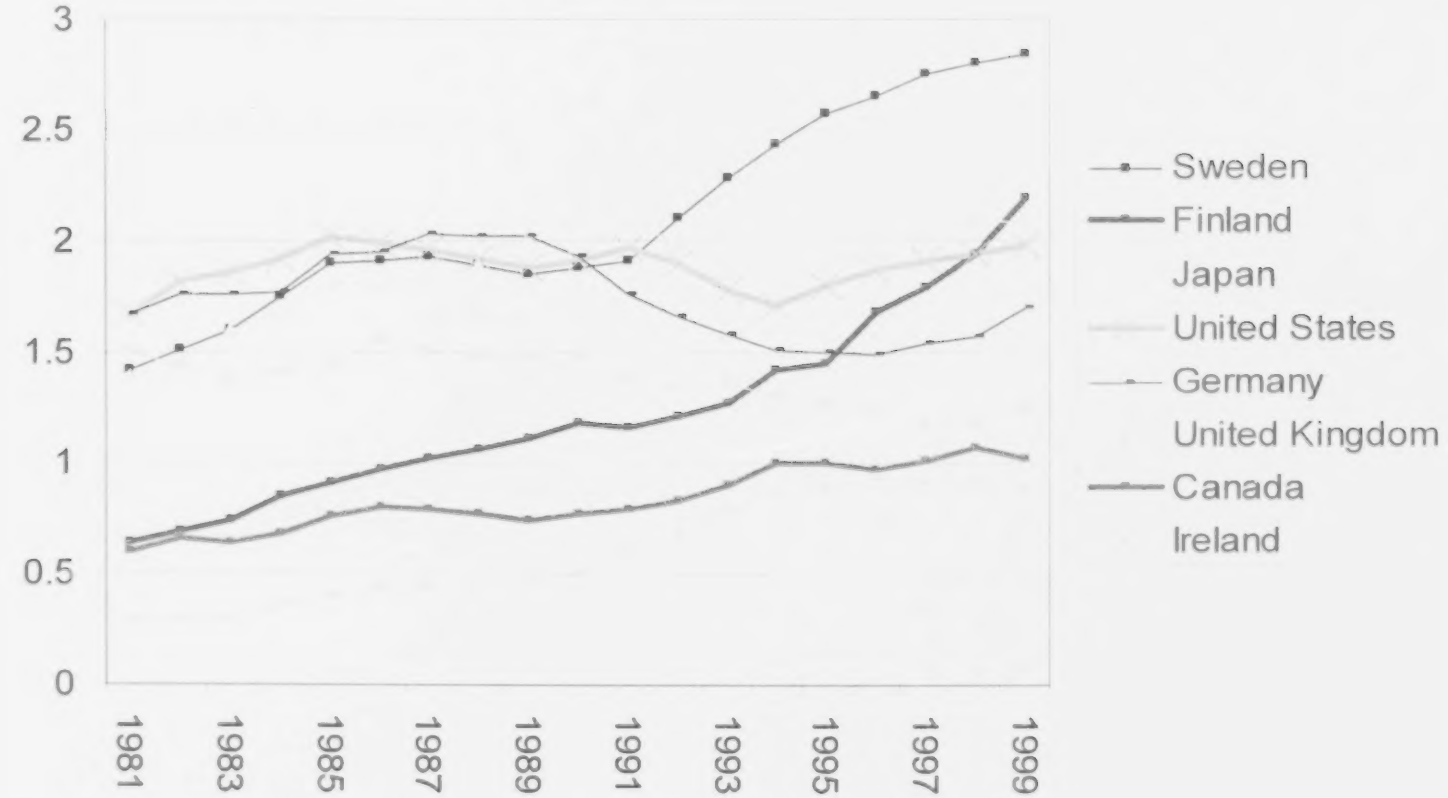


Table 4-51 of NSF(2004), http://www.nsf.gov/sbe/srs/seind04/append/c4/at04-51.xls

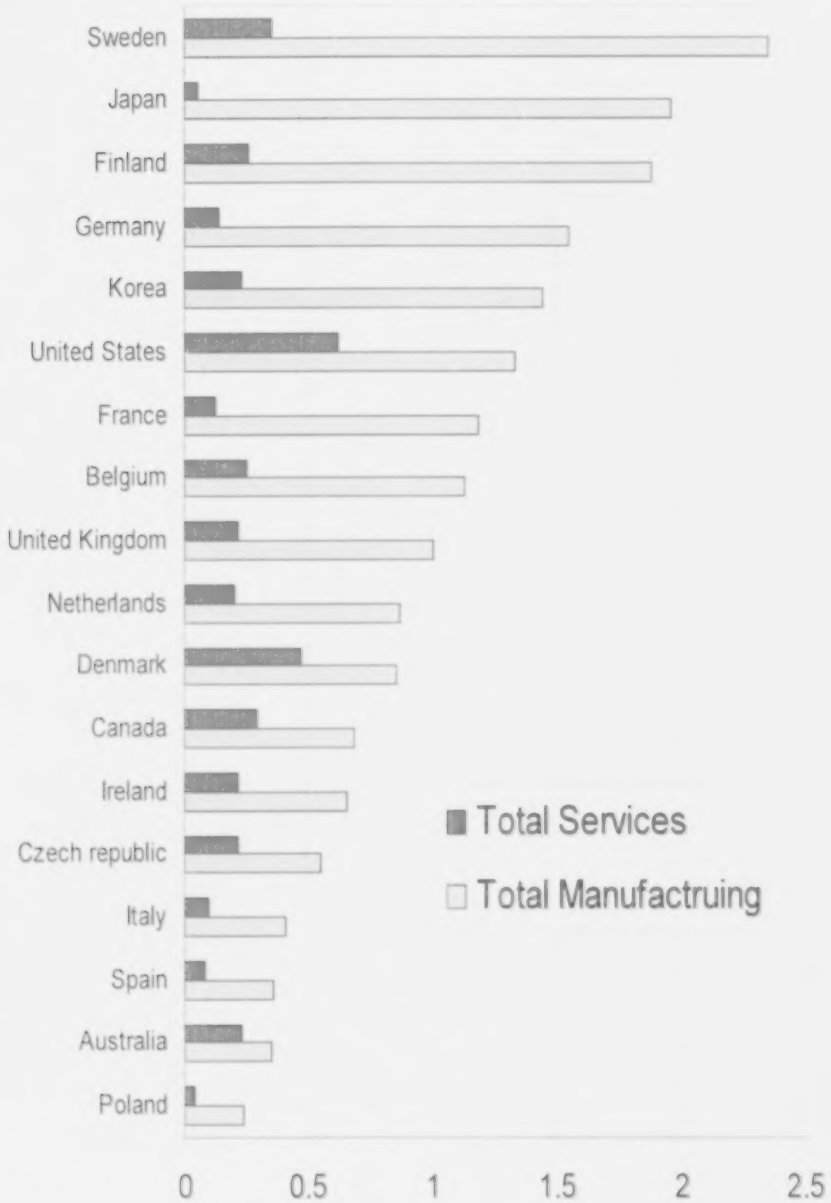
[66] The vertical axis represent the R&D undertaken by a U.S. firm in a foreign country divided by U.S. GDP and multiplied by a thousand to limit the number of decimal places.

Figure 10: Total Business R&D as a share of GDP, selected countries (rank in legend matches ranking in 1999).



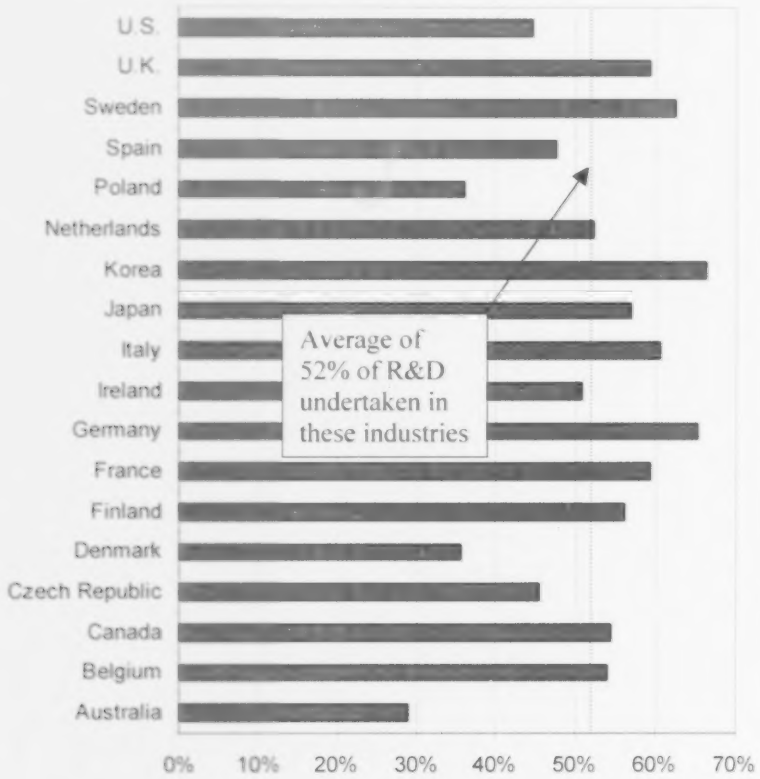
Source: OECD Main Science and Technology Indicators 2002-2

Figure 11: R&D as a percentage of GDP for total services and total manufacturing



Source: OECD R&D Expenditure by Industry Database

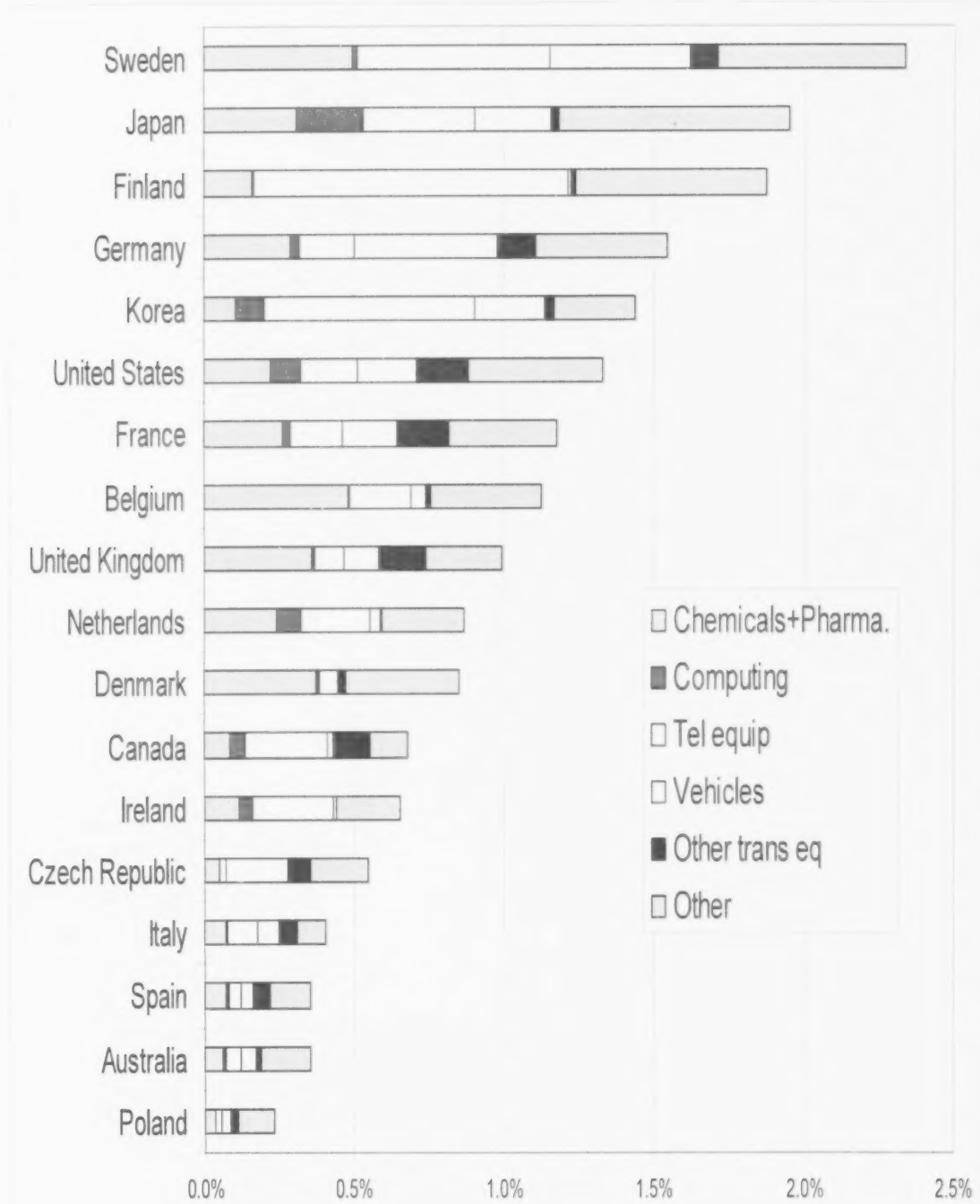
Figure 12: The proportion of aggregate research undertaken in research-intensive industries[67]



Source: OECD R&D Expenditure by Industry Database

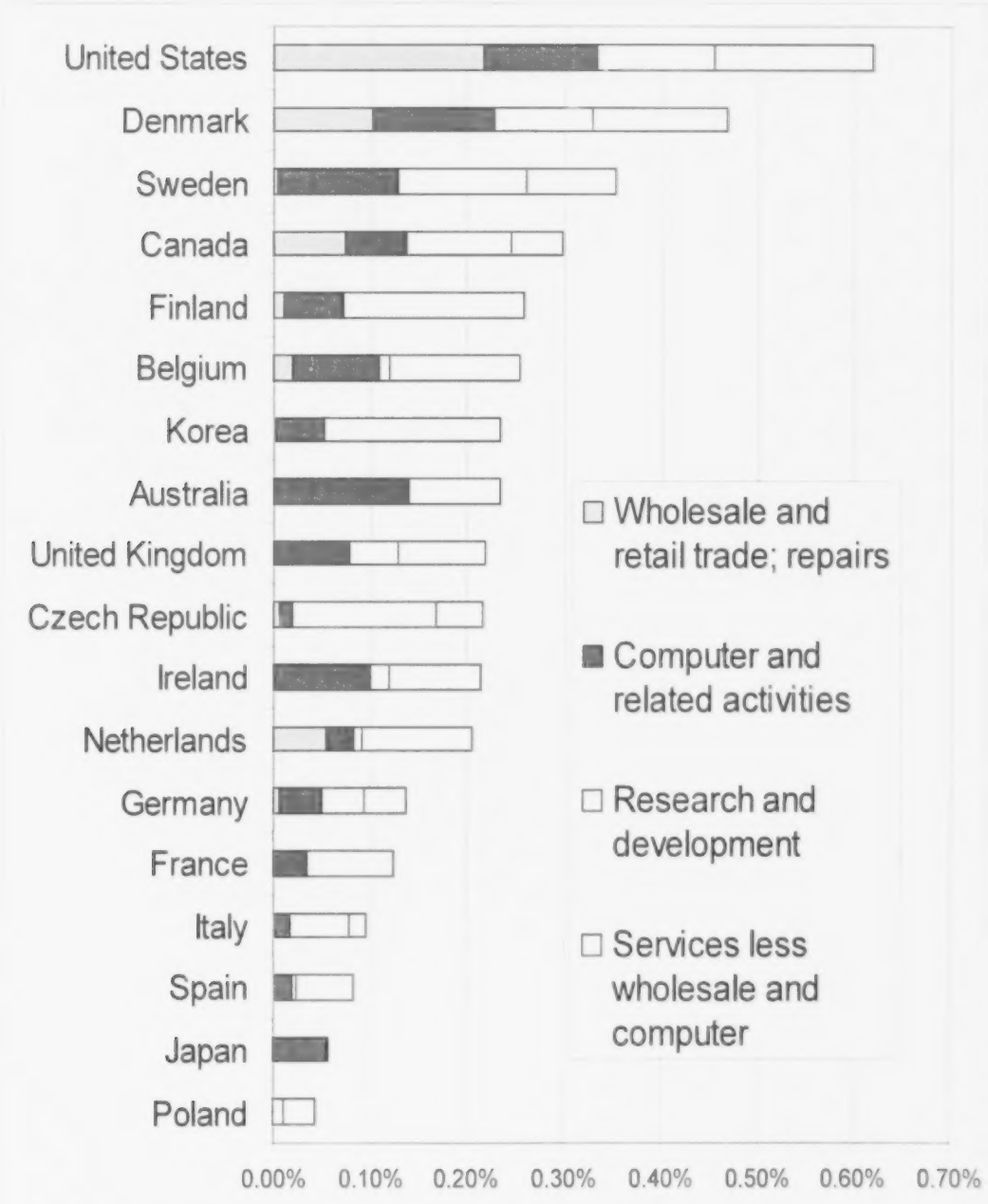
[67] These industries are chemical and pharmaceuticals; office, accounting and computing machinery; radio, television and communication equipment; motor vehicles and other transport equipment.

Figure 13: R&D as a percentage of GDP for manufacturing



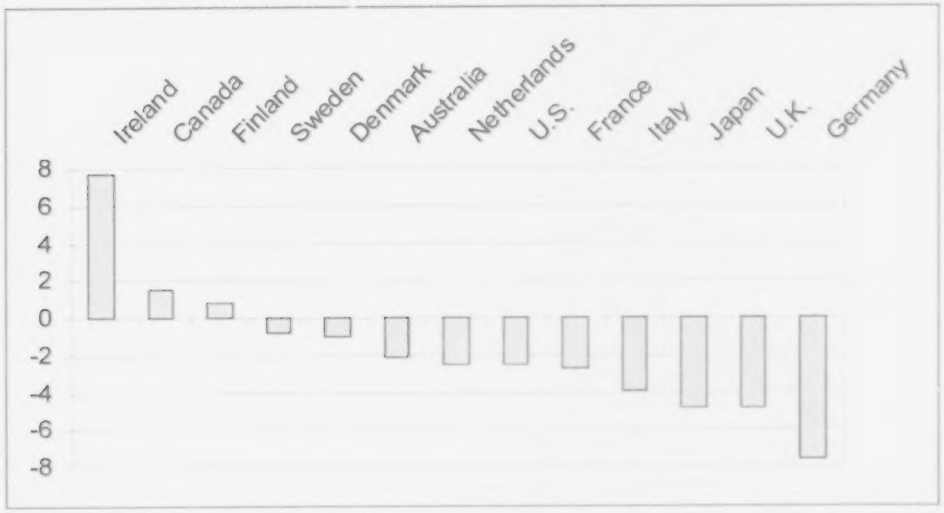
Source: OECD R&D Expenditure by Industry Database

Figure 14: R&D as a percentage of GDP for the services sector



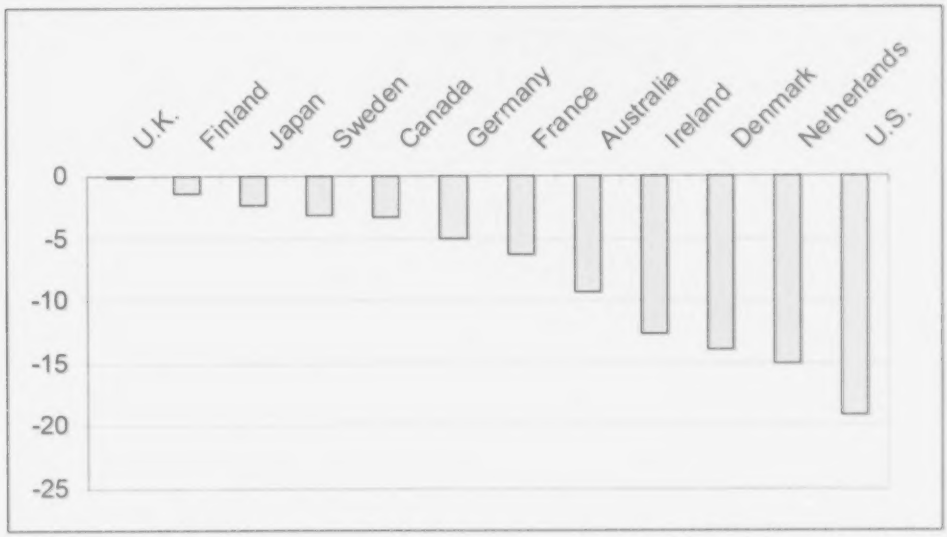
Source: Underlying data from the OECD R&D Expenditure by Industry Database

Figure 15: Percentage Point Change in the Share of Manufacturing in GDP (1989-1999)



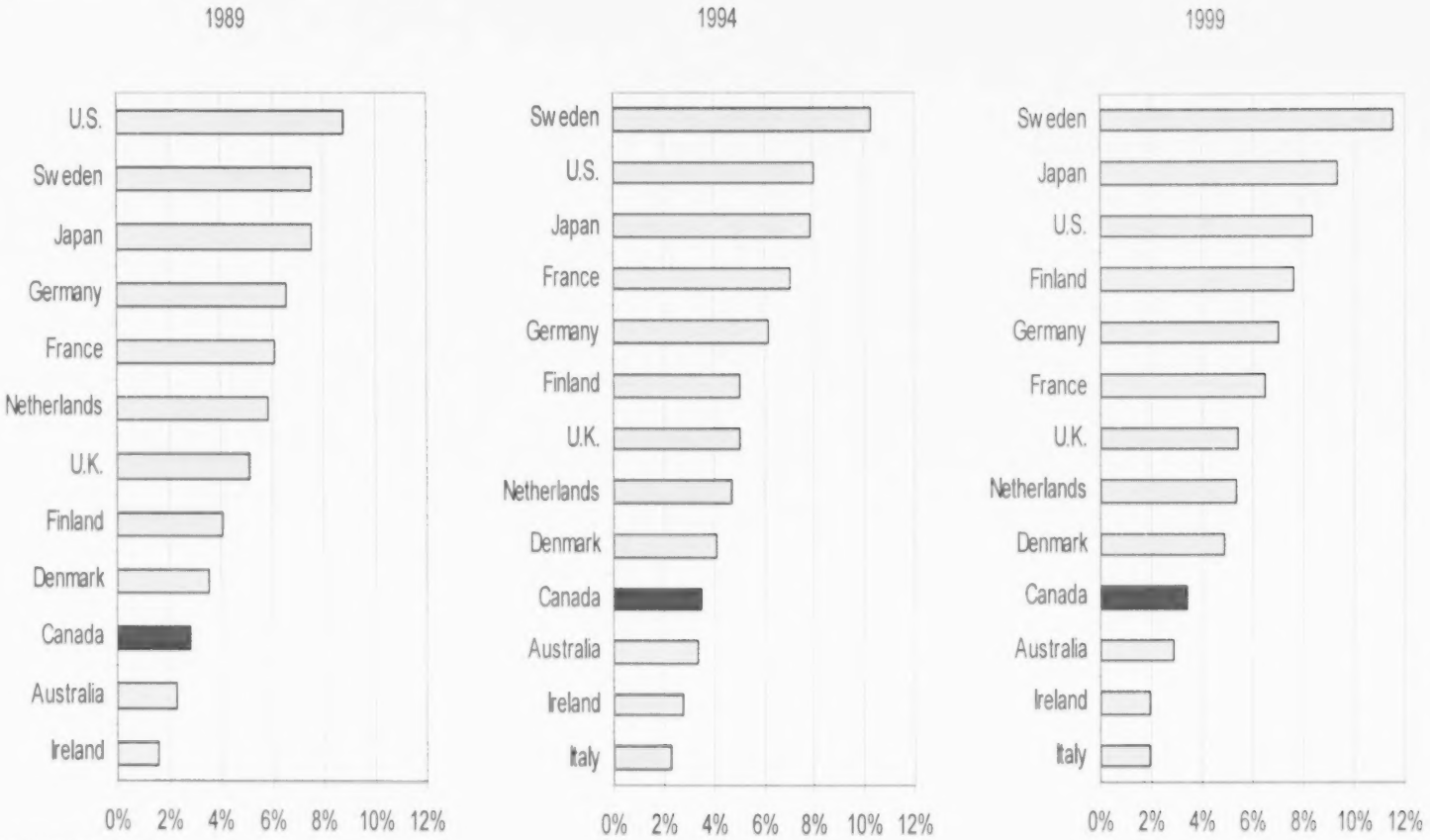
Source: OECD STAN Database

Figure 16: Percentage point decline in manufacturing R&D as a share of total R&D(1989-1999)



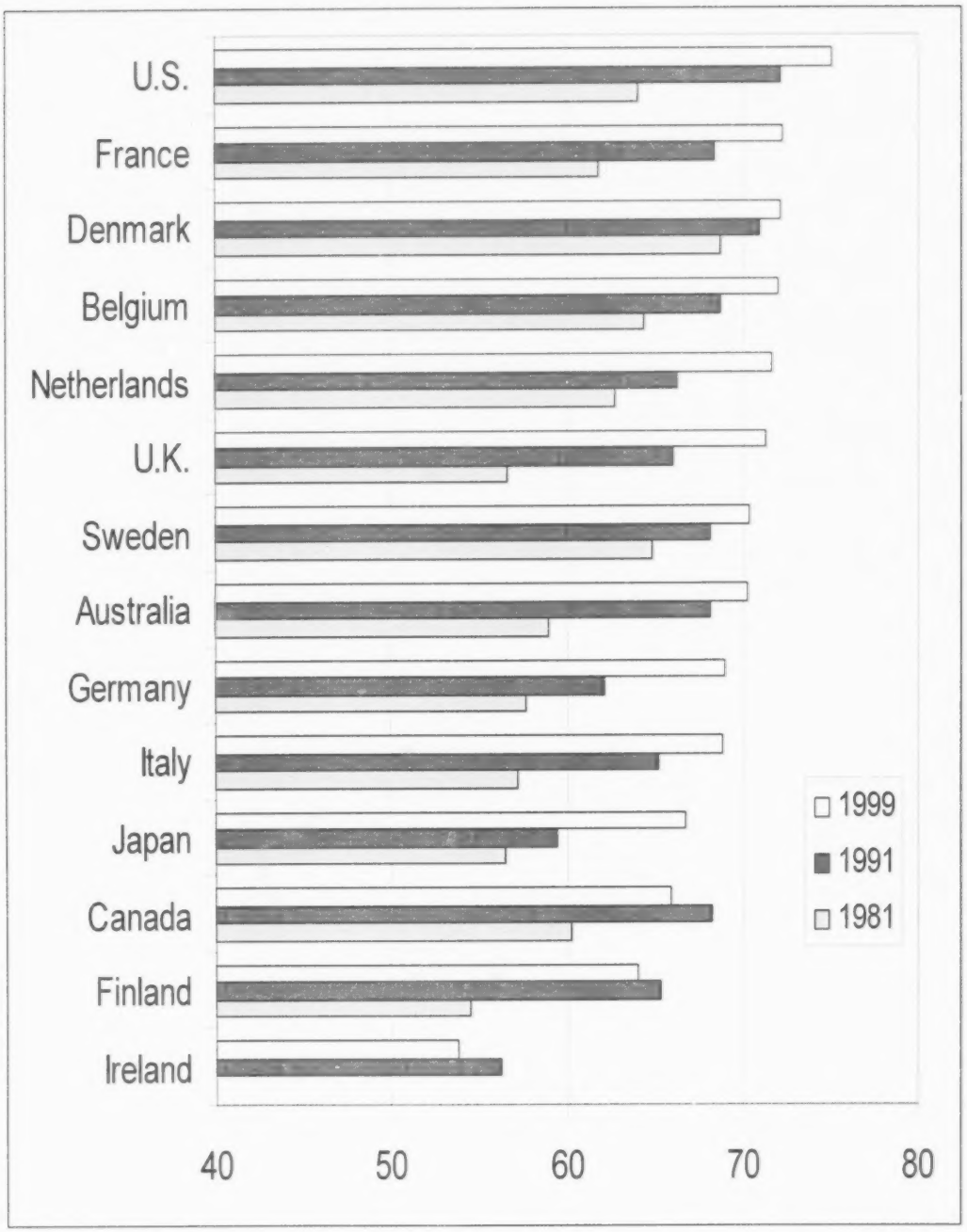
Source: OECD STAN Database

Figure 17: Own R&D intensity in manufacturing



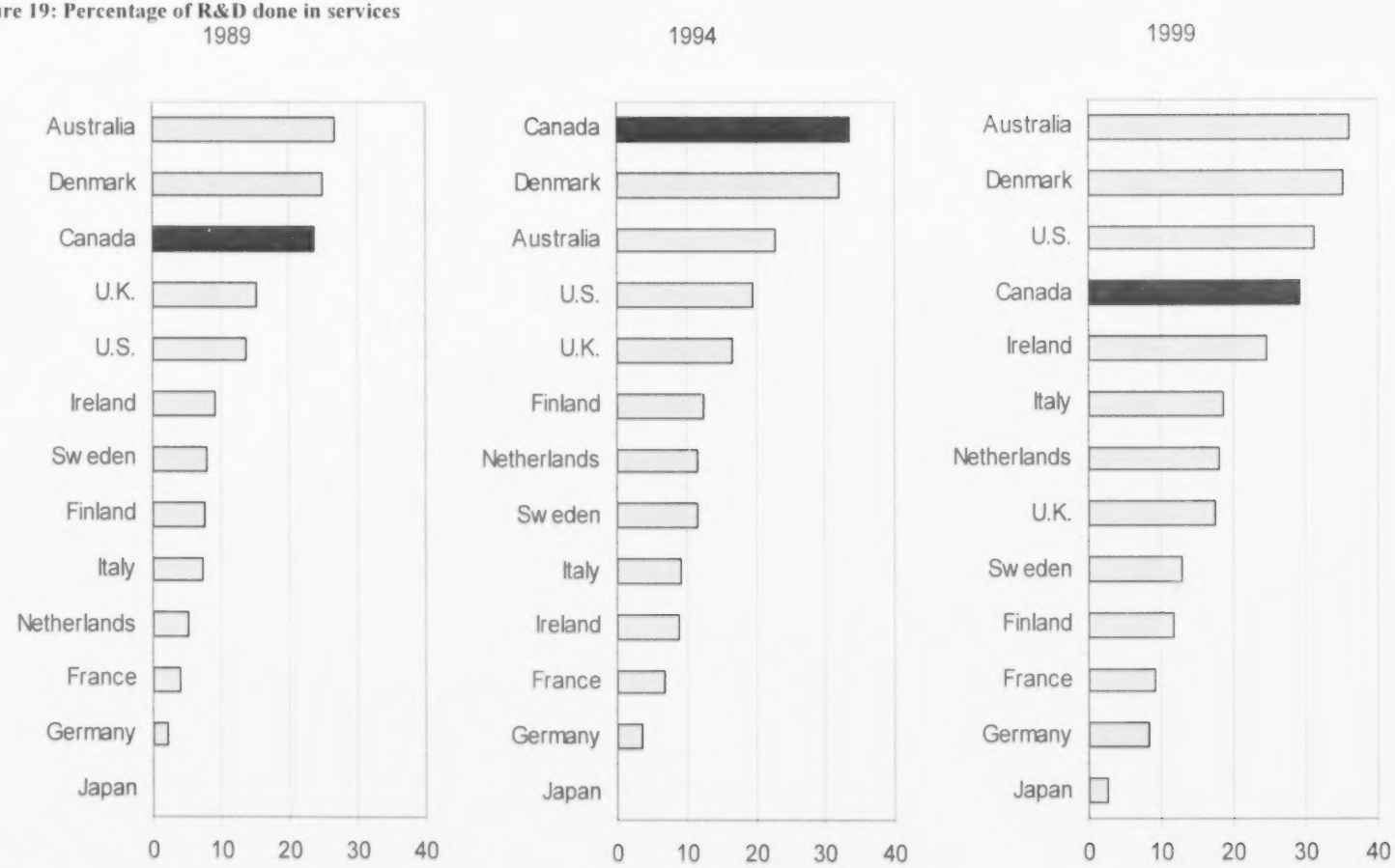
Source OECD STAN Database

Figure 18: Share of services in GDP (truncated axis)



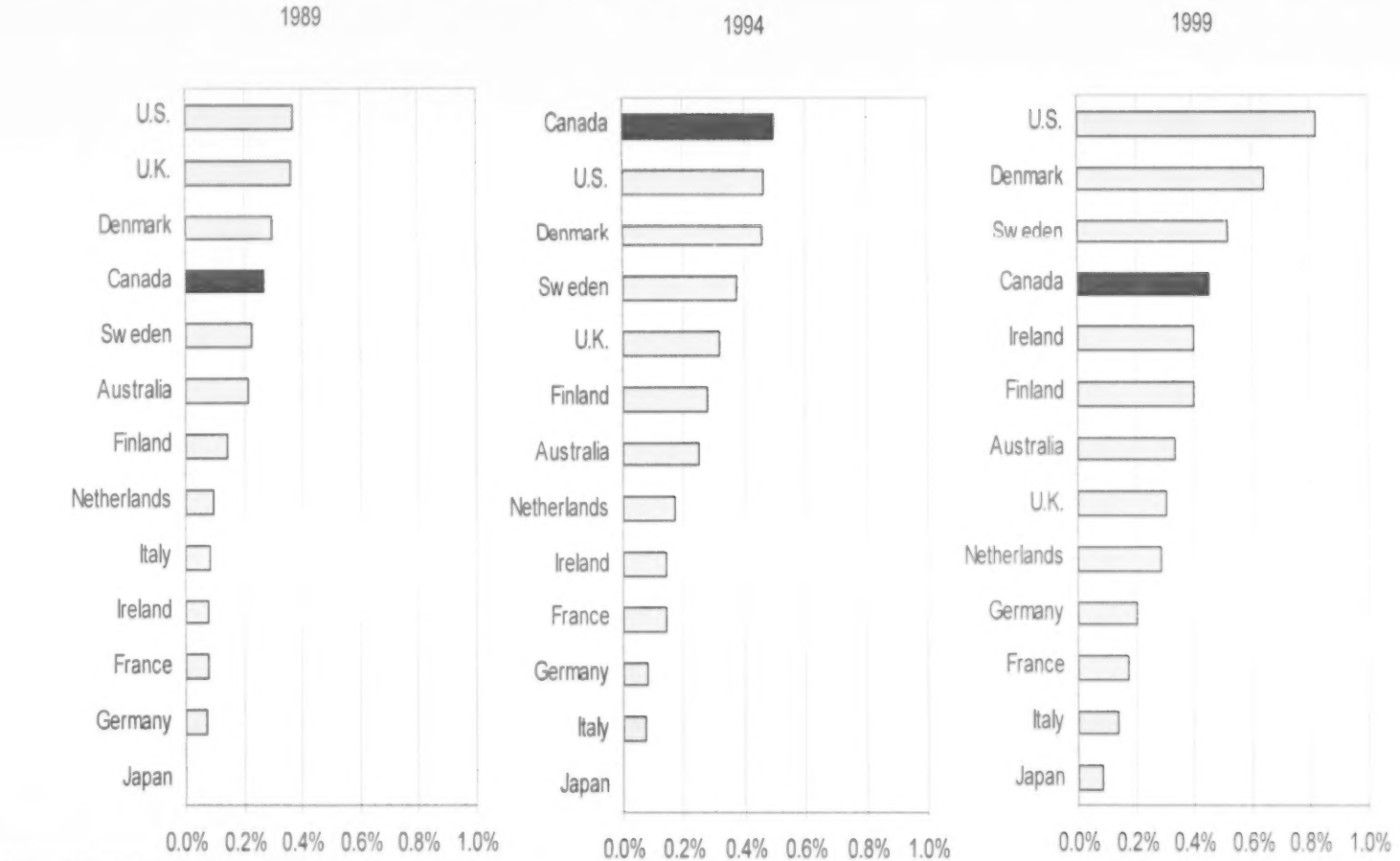
Source: OECD STAN Database

Figure 19: Percentage of R&D done in services



Source OECD STAN Database

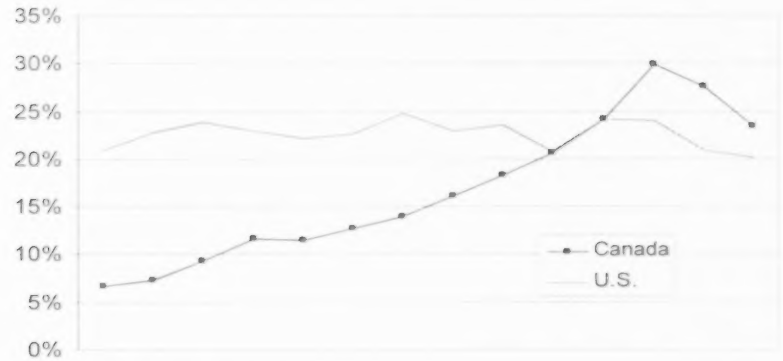
Figure 20: R&D intensity in the service sector (as a % of service sector value added)



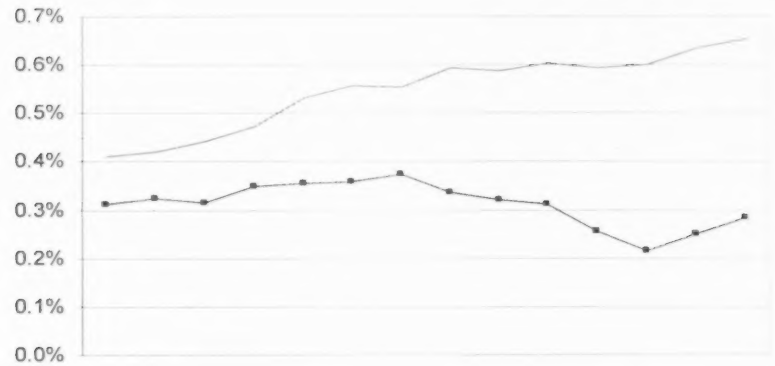
Source OECD STAN Database

Figure 21: Pharmaceuticals

Own Research Intensity



Share of pharmaceuticals in GDP

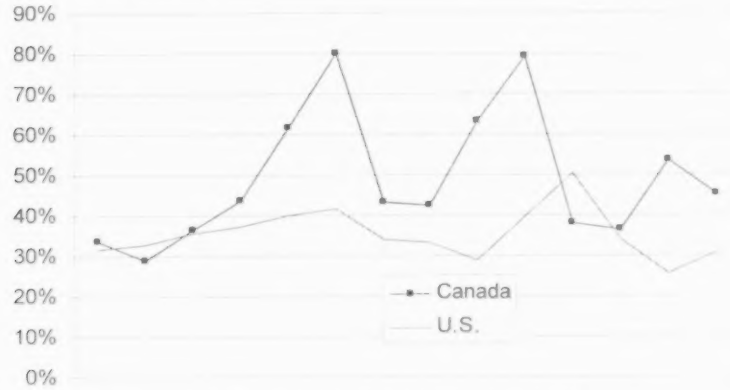


Contribution to aggregate R&D intensity (R&D as a share of GDP)

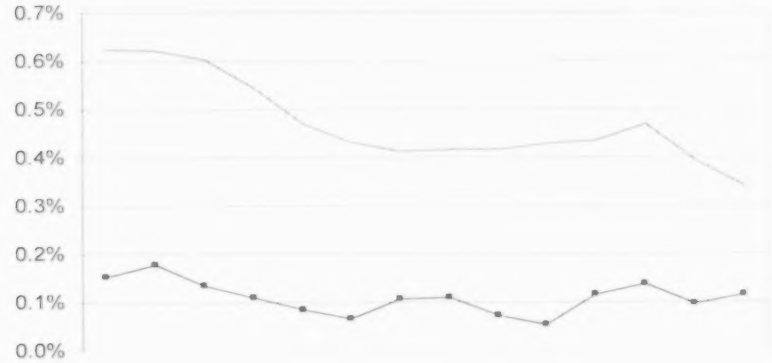
Sources: Underlying data from the OECD R&D Expenditure by Industry Database, The OECD STAN database for Industrial Analysis

Figure 22:Office, accounting and computing machinery

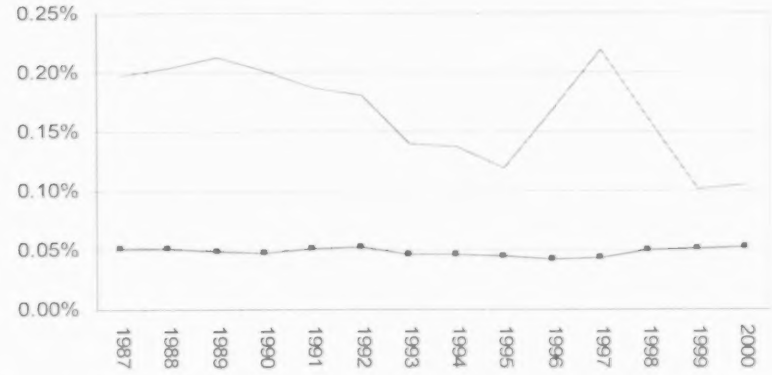
Own Research Intensity



Share of office, accounting and computing machinery in GDP



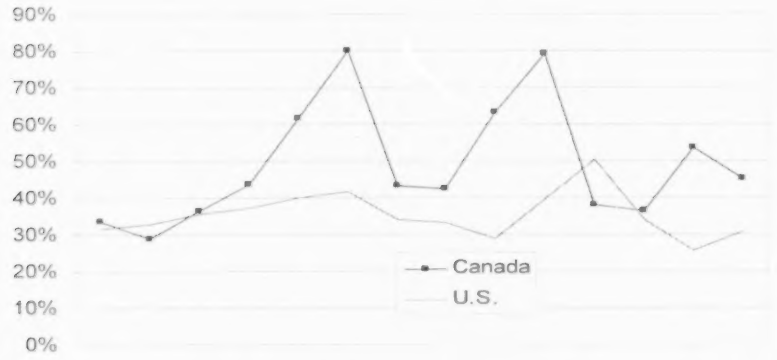
Contribution to aggregate R&D intensity (R&D as a share of GDP)



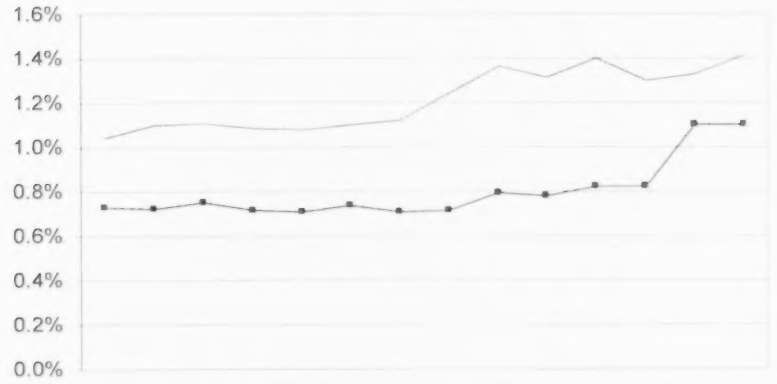
Sources: Underlying data from the OECD R&D Expenditure by Industry Database, The OECD STAN database for Industrial Analysis

Figure 23:Radio, television and communication equipment

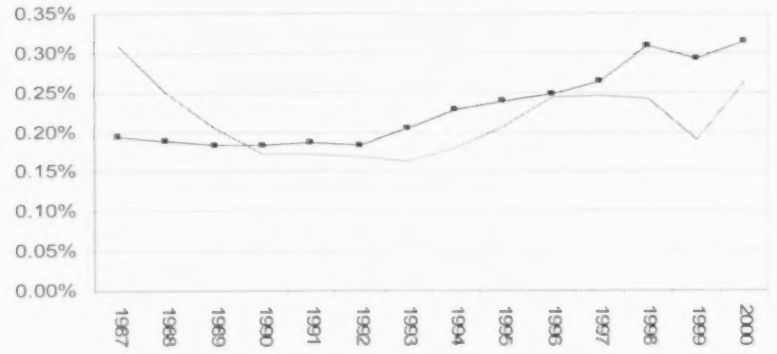
Own Research Intensity



Share of radio, television and communication equipment in GDP



Contribution to aggregate R&D intensity (R&D as a share of GDP)

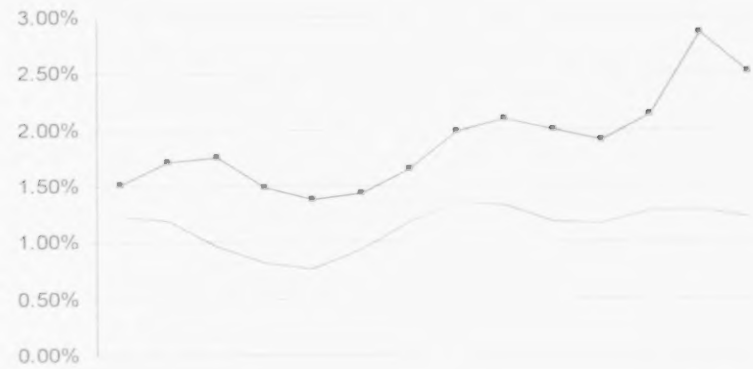


Sources: Underlying data from the OECD R&D Expenditure by Industry Database, The OECD STAN database for Industrial Analysis

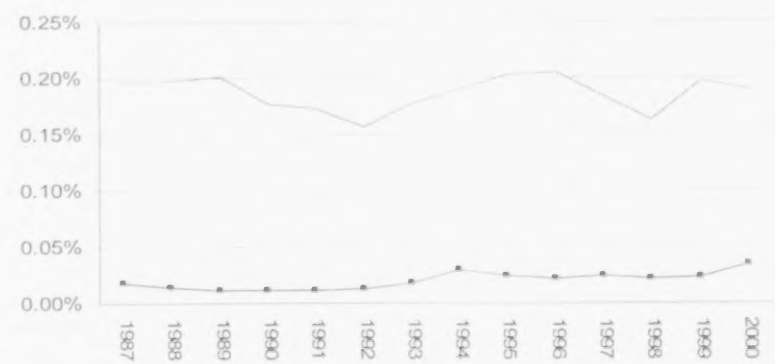
Figure 24: Motor Vehicles

Own Research Intensity

Share of motor vehicles in GDP



Contribution to aggregate R&D intensity (R&D as a share of GDP)

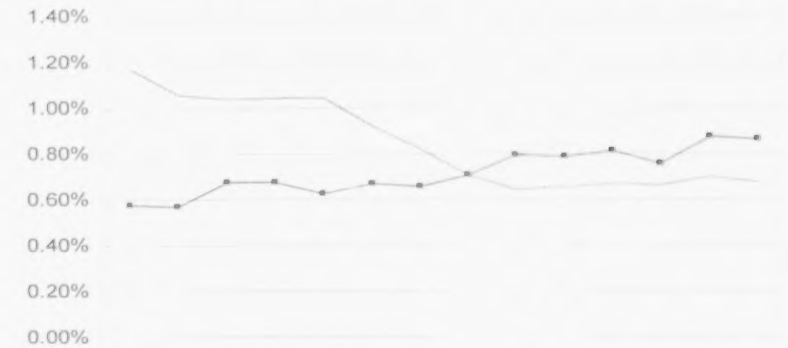


Sources: Underlying data from the OECD R&D Expenditure by Industry Database, The OECD STAN database for Industrial Analysis

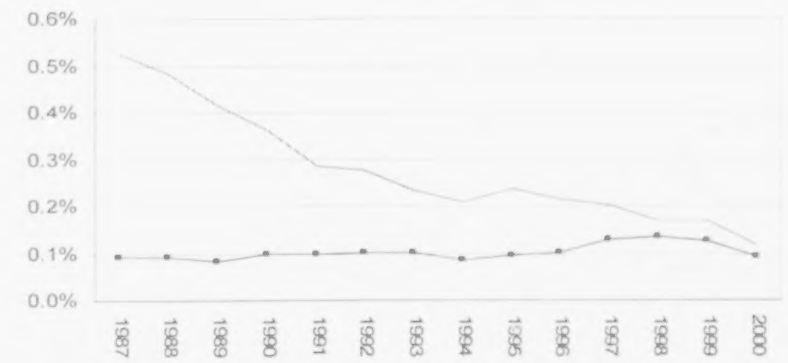
Figure 25:Other Transport Equipment

Own Research Intensity

Share of other transport equipment in GDP

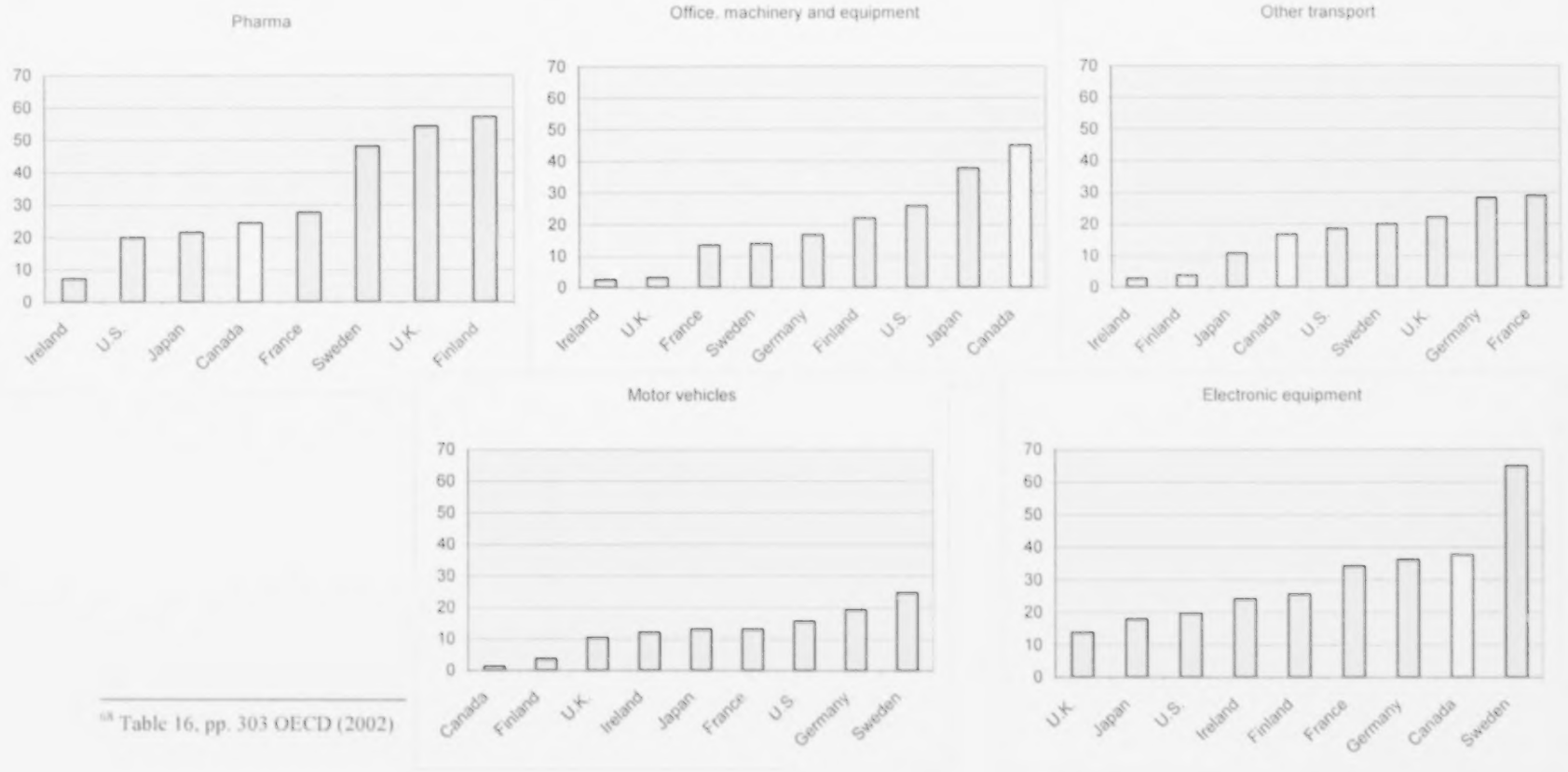


Contribution to aggregate R&D intensity (R&D as a share of GDP)



Sources: Underlying data from the OECD R&D Expenditure by Industry Database, The OECD STAN database for Industrial Analysis

Figure 26: R&D Intensity (as a percentage of value added) for high research intensity industries in selected countries and Canada (data for latest available year, Canada, U.S. for 1999)[68]



[68] Table 16, pp. 303 OECD (2002)